INTRODUCTORY COURSE

IN

MECHANICAL DRAWING

BY

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WITH CHAPTER ON PERSPECTIVE
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PREFACE

This book is intended for beginners. Its aim is to prepare the student for a more extended course in any one of the special lines of drafting. The endeavor has been to make the book comprehensive enough for use in schools and colleges, and, at the same time, to have it meet the needs of the student who must study the subject with little if any help from a teacher. In the preparation of the work the author has assumed:

1. That those who will use the book will have a working knowledge of, at least, the elements of geometry.

Hence geometrical definitions and constructions are omitted.

2. That machine drawing, bridge drawing, and other more advanced applications of mechanical drawing are better omitted from a course designed to be introductory to *any* kind of instrumental drawing.

3. That the success of any course depends largely upon the nature of its problems.

Hence each problem has been chosen for some definite principle it illustrates, and the whole so arranged as to form a progressive series. (See introduction to problems, page 1.)

4. That information worth giving to the beginner is worth giving in book form.

Hence the numerous and explicit directions and suggestions of the first three chapters, so grouped and arranged as to be easy of reference.

5. That in teaching mechanical drawing there is a *legitimate* use for models.

Hence the insertion of photographs throughout the book. The advantage of these photographs over ordinary models is obvious.

6. That orthographic projection, because of its importance, should have the fullest and most systematic treatment.

7. That in the treatment of orthographic projection a few of the fundamental principles of descriptive geometry must be made clear.

The use of photographs of models enables this to be done without plunging the student beyond his depth in abstract theory (Chaps. V. and VI. See Art. 65, page 47).

8. That a chapter of concise practical directions for perspective drawing will be welcomed by students and draftsmen who do not care to study a more extended treatise on the subject.

The author's friend and colleague, Mr. E. H. Lockwood, has had no small part in the preparation of this book. Mr. Lockwood and the author originally planned to write it together. Prevented from sharing in the actual work, the former has had at all times an author's interest in the book's success. He has placed at the author's disposal his pamphlet on Mechanical Drawing, and Chapter V. is a revision of a similar chapter in this pamphlet. In addition, Mr. Lockwood has kindly contributed Chapter VII., on perspective.

The author is also indebted to the following graduates and students of the Sheffield Scientific School: Messrs. Patterson, Hopton, Rogers, Hastings, Howarth, and Weaver, for contributing the drawings at the end of the book; and to Mr. L. D. Tracy, for checking the wording and dimensions in the manuscript of the problems.

J. C. TRACY.

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AN INTRODUCTORY COURSE IN MECHANICAL DRAWING

PROBLEMS

INTRODUCTORY

The problems here given constitute two distinct but parallel courses of twenty-six plates each. Any problem of course *a* can be substituted for the corresponding problem of the same plate, course *b*, or vice versa, without affecting the general plan. The courses *a* and *b* are, therefore, equivalent, and either one can be pursued, or a combination of both, thus enabling different plates to be arranged from year to year. The principles which these problems illustrate are explained in the succeeding chapters. The general directions for drawing the plates are given on page 2.

The problems for the most part are limited to geometrical solids, because these are easily described in print. The solids, however, are so combined as to furnish new and useful variations in many cases. The advantage to the student of drawing an object solely from a printed description is obvious.

In general, two exercises of one and one-half hours each will be required for a plate. The first three plates and two or three others may require additional exercises. From ninety to a hundred hours should be a sufficient time in which to complete either course as given. An instructor can easily adapt the course to longer or shorter exercises by changing the number of problems on a plate. Since each plate is divided into as many equal parts as there are problems, it is easy to estimate how much space should be allowed for each problem. Though the plates are intended to be $22'' \times 15''$, with a $21'' \times 14''$ border line, this size can be changed if the number of problems on each plate is also changed.

Only three plates are given in isometric and cabinet, as practice in these projections will be gained in illustrating orthographic projection. If time will allow it is a good plan to draw Plate II. in cabinet and Plate III. in isometric, thus introducing an additional plate in each of these projections.

In connection with the required course there is an optional course, consisting of drawings to be made *outside of* the regular exercises. This course aims to give practical applications of the principles taught in the regular course. It is designed for those students who intend to pursue one of the courses in engineering, as well as for all others who desire to gain a more practical knowledge of drawing than they otherwise would. Great freedom should be allowed in this course, and the student should be encouraged in original work. In this way the student can begin to make "working drawings." The instructor can by personal supervision make this part of the course of great value. By introducing optionals the required course can be lengthened; by omitting certain plates it can be abridged. Few beginners will be able to draw all the optionals; the instructor can recommend to each student those which will be of the most value to him.

The notes at the end of each plate are designed to aid the student. In many cases they warn him against common mistakes. The instructor should insist on the student reading these notes and studying the articles referred to in connection with a plate before beginning to draw that plate. The directions, which are numerous at first, decrease in number as the course progresses, and the student is better able to work without assistance.

Isometric and cabinet projections have been used in many plates to illustrate problems in orthographic projection. The finished figure or picture which results in any particular case is, perhaps, of little value. *The work necessary in*

drawing it, however, is of great value to the student in understanding orthographic projection. The instructor, however, should make it clear at the beginning that this is of no practical benefit *after* a knowledge of orthographic projection has been acquired. This method of teaching orthographic projection is unusual, but it has been tried with such success as to warrant its introduction in this course.

Special Directions for Making Plates.—For each plate of this course there will be a border line $14'' \times 21''$. The space within this border is to be subdivided into as many smaller equal rectangles as there are problems. Each figure is to be located symmetrically with respect to the sides of its own rectangle. See Art. 25 (*c*). When thought desirable the figure has been more definitely located by two co-ordinate distances (x and y) of some starting-point from the left-hand and lower sides of the rectangle; x represents the distance of this point from the left-hand side, and y from the lower side of the rectangle. Unless otherwise noted the starting-point is the lowest point of the figure; if there are two or more such points, the *left-hand* lowest point is chosen.

An article or note referred to at the end of a problem has special bearing on that problem. Never begin a plate or problem without reading the articles and notes thus indicated.

Problems are to be arranged in order lengthwise across the paper, each row beginning at the left-hand edge.

The number of the plate, as, for example, Plate I., should be printed below the centre of the upper edge of the paper, just above the border line, in letters about $\frac{2}{10}''$ or $\frac{3}{16}''$ high. Ink in the border line about $\frac{1}{32}''$ wide, and the lines between the different problems about as light as the pen will draw.

PLATE I

1 (*a*). Draw twelve horizontal lines, one under the other, $3\frac{1}{2}''$ long and $\frac{1}{4}''$ apart. At right angles to these, draw eight lines $\frac{1}{2}''$ apart, thus forming a rectangle $2\frac{3}{4}''$ wide by $3\frac{1}{2}''$ long, composed of seventy-seven smaller rectangles $\frac{1}{4}''$ by $\frac{1}{2}''$.

1 (*b*). Draw a rectangle the horizontal sides of which are $3\frac{1}{2}''$ long, the vertical sides $1\frac{1}{2}''$. Draw a second rectangle the horizontal sides of which are $1\frac{1}{2}''$ long, the vertical sides $2\frac{3}{4}''$. The centres of the two rectangles coincide. Subdivide the first rectangle by horizontal lines $3\frac{1}{2}''$ long and $\frac{1}{4}''$ apart. Subdivide the second rectangle by vertical lines $2\frac{3}{4}''$ long and $\frac{1}{4}''$ apart. The finished figure will then be composed of thirty-six $\frac{1}{4}''$ squares, twelve $\frac{1}{4}'' \times 1''$ rectangles, and twelve $\frac{5}{8}'' \times \frac{1}{4}''$ rectangles.

2 (*a*). Draw the figure of 1 (*a*) when the parallel lines in one direction are 30° lines; the parallel lines in the other direction will then be 60° lines. $x = 3\frac{1}{2}''$, $y = \frac{1}{4}''$. (Note *a*.)

2 (*b*). Draw the figure of 1 (*b*) when the parallel lines in one direction are 30° lines; the parallel lines in the other direction will then be 60° lines. (Note *b*.)

3 (*a*). Draw the figure of 1 (*a*) when the parallel lines in one direction are 45° lines; the parallel lines in the other direction will also be 45° lines. $x = 2\frac{1}{8}''$, $y = \frac{1}{8}''$.

3 (*b*). Draw the figure of 1 (*b*) when the parallel lines in one direction are 45° lines; the parallel lines in the other direction will also be 45° lines.

4 (*a*). Draw the figure of 1 (*a*) when the parallel lines in one direction are 15° lines; the parallel lines in the other direction will then be 75° lines. $x = 4''$, $y = \frac{9}{16}''$. (Note *c*.)

4 (*b*). Draw the figure of 1 (*b*) when the parallel lines in one direction are 15° lines; the parallel lines in the other direction will then be 75° lines. (Note *c*.)

GEOMETRICAL CONSTRUCTIONS

5 (*a*). Given a horizontal line $4\frac{1}{2}''$ long. At the centre of this line erect a perpendicular line extending $1\frac{5}{16}''$ above and $1\frac{5}{16}''$ below the given line. Use the compasses only in finding the perpendicular.

5 (*b*). Same as 5 (*a*), except that the given line is a 30° line.

6 (*a*). A 30° line $3\frac{7}{16}''$ long and a 75° line $3\frac{1}{16}''$ long meet in a point, forming an acute angle. By means of the compasses bisect this angle by a third line $4\frac{3}{8}''$ long. $x = 1\frac{1}{8}''$, $y = \frac{9}{16}''$ (to vertex of angle). (Note *d*.)

6 (*b*). Same as 6 (*a*), except that the given lines are 15° and 60° lines respectively. $x = 1''$, $y = \frac{3}{4}''$ (to vertex of angle). (Note *d*.)

7 (*a*). Given a 30° line $3\frac{7}{16}''$ long. Divide it by a geometrical construction into nine equal parts. $x = 1\frac{1}{8}''$, $y = \frac{9}{16}''$. (Note *e*.)

7 (*b*). Same as 7 (*a*), except that the given line makes any unknown angle with the horizontal. (Note *e*.)

8 (*a*). Given a circle $2''$ in diameter. From any point $3\frac{3}{16}''$ from the centre of the circle draw two geometrically constructed tangents to that circle. $x = 1\frac{1}{2}''$, $y = 2\frac{5}{16}''$ (to centre of circle).

8 (*b*). Same as 8 (*a*), assuming the point anywhere outside the circle.

9 (*a*). Draw a 4″ circle and by means of the protractor inscribe a pentagon.

9 (*b*). Draw a 4″ circle and by means of the protractor inscribe a nonagon.

10 (*a*). Using only the scale, T-square, and triangles, draw a hexagon two sides of which are vertical. The length of a side is 2″.

10 (*b*). Using only the scale, T-square, and triangles, draw a hexagon two sides of which are horizontal. The length of a side is 2″.

11 (*a*). Using only the scale, T-square, and triangles, draw an octagon two sides of which are horizontal. The length of a side is $1\frac{1}{2}$″. (Note *f*.)

11 (*b*). Using only the scale, T-square, and triangles, draw an octagon no side of which is horizontal. The length of a side is $1\frac{1}{2}$″. (Note *f*.)

12 (*a*). Draw a 4″ circle. Using only the T-square and triangles, divide this circle into twenty-four equal sectors. (Note *g*.)

12 (*b*). Draw a 4″ square; from each of its corners draw an arc of a circle terminating in the middle points of two sides of the square. Divide each quadrant of a circle thus formed into six equal parts, using only the T-square and triangles.

NOTES—PLATE I

This plate is given to practise the student in the use of the instruments. It is to be drawn in pencil at the first exercise and inked in at the second.

Exercise 1

Before beginning this exercise read Arts. 14–16, 18 (*a*), (*b*), (*c*), 19, 20 (*a*), 23–27, 29–32, and the special directions for making plates, page 2.

Draw a border line 14″ × 21″ and divide the enclosed space into twelve equal spaces. Place first four figures in the upper row.

(*a*) In 2 (*a*), 3 (*a*), and 4 (*a*) the larger portion of the figure is to the left of the point located by x and y.

(*b*) In 2 (*b*), 3 (*b*), and 4 (*b*) the centre of each figure is in the centre of its rectangle.

(*c*) See Art. 16 (*c*), Figs. 4 and 5, and Arts. 16 (*d*), (*e*), (*f*), Figs. 6, 7, and 8.

(*d*) In 6 (*a*) and 6 (*b*) both lines forming the angle extend to the right of the point located by x and y.

(*e*) In 7 (*a*) and 7 (*b*) use triangles for drawing the parallel lines. See Art. 16 (*d*).

(*f*) In 11 (*a*) and 11 (*b*) the distance between any two parallel sides of the octagon is about $3\frac{5}{8}$″.

(*g*) See Art. 16 (*c*).

Exercise 2

Before inking the plate read carefully Arts. 17, 18 (*d*), (*e*), (*f*), (*g*), 28, 29 (*b*), (*c*), 33. In geometrical problems ink in given and required lines full. Construction lines are small, fine dashes. See Art. 32 (*b*). The student is to use his judgment in lettering geometrical figures to make them clearer. For example, in Prob. 6 (*a*) it might be well to print on the lines "30° LINE," "75° LINE," and "BISECTOR" respectively.

See Special Directions, page 2, for title and border lines.

OPTIONAL

1 (*a*). Free-hand Lettering.—Print the lower-case letter *a*. (See Fig. 9, Reinhardt's book on lettering. See Art. 33.) Indicate by numbers and arrows the sequence and directions of the strokes, leaving small breaks between the strokes. This shows the method of forming the letter. Under this *a* print a horizontal line of several *a's*, omitting numbers, arrows, and breaks. Treat each letter of the lower-case alphabet and each capital letter in a similar manner. Make the letters about the same size as those in Reinhardt's book. Use not more than two pencil guide-lines, one for the top and one for the bottom of the letters. The arrangement of the whole plate is left to the taste of the student.

When the student can do this optional well the instructor can arrange several others, including one which groups the letters into words, and one on letters of the Block, Egyptian, and Roman systems, made free-hand and with the instruments. If time allows it is well to give a course in lettering as part of the regular required course.

1 (*b*). [To be drawn instead of 1 (*a*) when lettering is part of the required course.] Draw an original geometrical design of straight lines, circles, and arcs of circles. Aim at symmetry and accuracy as well as a graceful, pleasing effect.

PLATE II

ISOMETRIC PROJECTION

Make an isometric drawing of:

1 (*a*). A rectangular block $1'' \times 1\frac{1}{2}'' \times 3''$ standing on a $1'' \times 1\frac{1}{2}''$ end. $x = 3\frac{5}{16}''$, $y = 1\frac{3}{8}''$.

1 (*b*). The same block as in 1 (*a*) when it is lying on a $1\frac{1}{2}'' \times 3''$ face. $x = 2\frac{13}{16}''$, $y = 1\frac{7}{8}''$.

2 (*a*). A block $2\frac{1}{2}''$ square and $\frac{3}{4}''$ high; in the centre of the upper face of this block stands a second block $1\frac{1}{2}''$ square and $\frac{3}{4}''$ high; in the centre of the upper face of the second block stands a third block $\frac{1}{2}''$ square and $\frac{3}{4}''$ high. The corresponding edges of the three blocks are parallel. $x = 3\frac{1}{2}''$, $y = 1\frac{5}{8}''$.

2 (*b*). A block 1″ high; the base on which it stands is $1\frac{1}{2}'' \times 3''$; the top face is $1'' \times 3''$; the two sides have the same slope. $x = 2\frac{13}{16}''$, $y = 1\frac{15}{16}''$.

3 (*a*). A block $\frac{3}{4}''$ high; the lower base is $1\frac{1}{2}''$ square; the upper base is 1″ square; the sides all have the same slope. Standing on this block is a prism 1″ square and 2″ high, upon the top of which rests a third block exactly like the first except it is inverted, its 1″ square base coinciding with the upper base of the prism. The centres of all bases are in a straight line. $x = 3\frac{1}{2}''$, $y = 1''$. (Note *a*.)

3 (*b*). Same as 3 (*a*) when the axis passing through the centres of the three blocks is horizontal instead of vertical. $x = 2\frac{11}{16}''$, $y = 1\frac{1}{2}''$. (Note *a*.)

4 (*a*). A hollow $2\frac{1}{2}''$ cube; the thickness of sides is $\frac{1}{4}''$. In the centre of each face is an open hole $1\frac{1}{2}''$ square; the edges of the holes are parallel to the corresponding edges of the cube. $x = 3\frac{1}{2}''$, $y = 1''$.

4 (*b*). A hollow hexagonal prism 3″ long; a side of the outside hexagon is $\frac{7}{8}''$ long. The perpendicular distance between the outside and inside surfaces is $\frac{3}{16}''$. Half-way between the two ends there is a continuous raised rectangular strip 1″ wide by $\frac{3}{16}''$ thick extending entirely around the outside of the prism. The 1″ is measured parallel to a 3″ edge of the prism. Assume two faces of the prism to be horizontal, the two ends of the prism being vertical. $x = 4''$, $y = 1\frac{3}{8}''$ (to corner of rectangle in which largest hexagon of right end is inscribed. Figure extends to the left). (Note *b*.)

5 (*a*). A solid which has for its front end a rectangle 2″ wide by $1\frac{1}{2}''$ high; its rear end is $2\frac{1}{2}''$ wide by 2″ high; the perpendicular distance between the two ends is $3\frac{1}{2}''$; the four sides all have the same slope. Through the centre of each of these four sides there is a groove $\frac{1}{4}''$ deep (measured parallel to ends of block), running lengthwise. These grooves are each $\frac{1}{2}''$ wide at the smaller end of the block and $\frac{3}{4}''$ wide at the larger end. Assume the two ends of the block to be vertical. $x = 2\frac{3}{4}''$, $y = 1\frac{3}{16}''$.

5 (*b*). A $2\frac{1}{2}''$ cube; in the centre of each face there is a raised block 1″ square by $\frac{1}{4}''$ thick. The edges of the blocks are parallel to the corresponding edges of the cubes. $x = 3\frac{1}{2}''$, $y = 1''$.

6 (*a*). A hexagonal prism $3\frac{1}{2}''$ high; side of hexagon $1\frac{1}{4}''$; prism stands on a hexagonal end. Half-way up the prism there is a rectangular groove 1″ wide by $\frac{1}{4}''$ deep extending entirely around the prism at right angles to its edges. $x = 3\frac{5}{16}''$, $y = \frac{3}{4}''$ (to the corner of rectangle in which lower base is inscribed). (Note *b*.)

6 (*b*). A hexagonal pyramid $3\frac{1}{2}''$ high; side of hexagonal base is $1\frac{1}{4}''$ long. Half-way up the sides of the pyramid is a groove extending entirely around the pyramid. This groove is formed by removing the portion of the pyramid between two cuts, each $\frac{1}{4}''$ deep. The planes of both cuts are parallel to the plane of the base of the pyramid. The perpendicular distance between the planes of the two cuts is 1″. $x = 3\frac{5}{16}''$, $y = 1\frac{3}{16}''$ (to corner of rectangle in which base is inscribed). (Note *c*.)

NOTES—PLATE II

Before beginning the plate, study Arts. 46, 47, 48.

The distances given for x and y hold good in unsymmetrical figures only when the larger portion of the figure extends to the right of the point located. See Art. 47 *c*. An exception is in 4 (*b*).

The edges which cast shadows should be represented by heavier lines than are the other edges (Art. 53). First draw all light lines on the plate with one setting of the pen, and then draw shade lines. Thus, if a mistake is made in the first set of lines, it is more easily corrected than if heavy lines were drawn first. Do not make shade lines too heavy.

(*a*) In 3 (*a*) the $\frac{3}{4}''$ is the perpendicular, *not* the slant height. The *front* edge of the lower block will therefore be longer than $\frac{3}{4}''$. See Fig. 22, page 41.

(*b*) In 4 (*b*) and 6 (*a*) draw on a waste piece of paper a true hexagon, and proceed according to Art. 48.

(*c*) In 6 (*b*) it is evident that the portion of the pyramid removed is *not* $\frac{1}{4}''$ thick—the $\frac{1}{4}''$ being measured parallel to the plane of the base. The groove, likewise, is more than 1″ wide if measured parallel to the plane of a side face.

OPTIONAL II

Make an isometric drawing of one of the following objects:

1 (*a*). A shallow box (about 8″ square and 2″ deep) divided into four equal compartments by two cross-pieces at right angles to each other. The ends of the cross-pieces set into vertical grooves in the sides of the box. Each cross-piece is notched half its depth for the other cross-piece.

1 (*b*). Same as 1 (*a*) except that the bottom of the box is smaller than the top and the sides all have the same slope.

1 (*c*). A box with drawer or drawers for a card catalogue.

1 (*d*). A printing-frame for photographs.

1 (*e*). A small book-case or set of book-shelves.

1 (*f*). A small cabinet for minerals.

1 (*g*). A flower-stand.

1 (*h*). A tool-chest.

NOTE.—Original designs are preferable to drawings made from measurement. Dimensions may or may not be given on the drawing. Any simple rectangular object approved by the instructor may be chosen in place of one given if the student so desires.

PLATE III

CABINET PROJECTION

Make a drawing in cabinet projection of:

1 (*a*). A rectangular block 2″ high standing on a base 3″ square. In the centre of the upper face there is a rectangular hole 2″ square by $\frac{3}{8}''$ deep; the edges of the hole are parallel to the corresponding edges of the block. $x=1\frac{7}{16}''$, $y=2''$.

1 (*b*). Same block as in 1 (*a*) when it is standing on a 2″ by 3″ face. Let the face with the square hole be the side face shown. $x=2''$, $y=1\frac{1}{2}''$.

2 (*a*). Three cylinders, A, B, and C, each $1\frac{1}{2}''$ long; cylinder A is 1″ in diameter, B 2″ in diameter, and C 3″ in diameter. These cylinders are all horizontal, with their axes in the same straight line at right angles to the plane of the paper. The rear end of A is in contact with the front end of B, and the rear end of B is in contact with the front end of C. Thus the distance from the front end of A, which is in the plane of the paper, to the rear end of C is $4\frac{1}{2}''$. $x=2\frac{3}{16}''$, $y=2\frac{3}{16}''$ (to centre of circle in plane of paper).

2 (*b*). Same problem as 2 (*a*), substituting hexagonal prisms for the cylinders. The lengths of the sides of the hexagons are: For prism A $\frac{1}{2}''$, prism B 1″, prism C $1\frac{1}{2}''$. $x=2\frac{3}{16}''$, $y=2\frac{5}{16}''$ (to centre of hexagon in plane of paper).

3 (*a*). A rectangular block 4″ square by $1\frac{3}{8}''$ high. In the upper face of the block are four rectangular holes, each $1\frac{1}{4}''$ square by $\frac{1}{4}''$ deep; the edges of the holes are parallel to the corresponding edges of the block, and the distance between any outside edge of a hole and the nearest edge of the block is $\frac{1}{2}''$. $x=\frac{3}{4}''$, $y=2\frac{1}{16}''$.

3 (*b*). Same block as in 3 (*a*) when it is standing on a $1\frac{3}{8}''\times 4''$ face. Let the face with the square holes in it be the side face shown. $x=2\frac{1}{8}''$, $y=\frac{3}{4}''$.

4 (*a*). A rectangular block 4″ square by $1\frac{1}{2}''$ high. In the upper face there are two rectangular grooves 1″ wide by $\frac{1}{4}''$ deep running diagonally from corner to corner at right angles to each other. The centre line of each groove coincides with the corresponding diagonal of the upper face of the block. $x=\frac{3}{4}''$, $y=2''$.

4 (*b*). A rectangular block 4″ square by $1\frac{1}{4}''$ high with raised diagonal strips 1″ wide by $\frac{1}{4}''$ high (total height $1\frac{1}{2}''$). The block in this problem is the reverse of that in 4 (*a*), the raised portion of 4 (*b*) fitting the grooves of 4 (*a*). $x=\frac{3}{4}''$, $y=2''$.

5 (*a*). A rectangular block 4″ square by $\frac{1}{2}''$ high. In the centre of the upper face of this block stands the frustum of a hexagonal pyramid. A side of the hexagon of the lower base is $1\frac{1}{2}''$; of the upper base $\frac{3}{4}''$. Two sides of the lower hexagon are perpendicular to the front edge of the rectangular block. The frustum is $2\frac{1}{2}''$ high. $x=\frac{3}{4}''$, $y=1\frac{1}{2}''$.

5 (*b*). The prisms of 2 (*b*) when the common axis of the three prisms is vertical instead of horizontal. Let the largest prism be at the bottom, and let two faces of each prism be parallel to the plane of the paper. $x=1\frac{9}{16}''$, $y=1''$ (to corner of rectangle in which lowest base is drawn).

6 (*a*). A $2\frac{3}{4}''$ cube. A continuous raised strip $\frac{1}{2}''$ wide by $\frac{1}{8}''$ high passes through the centres of the front, top, back, and bottom faces parallel to two sides of each face. There are two similar strips around the cube—one through the centres of the top, side, and bottom faces; the other through the centres of the front, side, and back faces. $x=1\frac{5}{8}''$, $y=1\frac{5}{8}''$ (to corner of cube).

6 (*b*). A 3″ cube. Through the centres of the front, top, back, and bottom faces there is a continuous groove $\frac{3}{4}''$ wide by $\frac{3}{16}''$ deep. The groove is parallel to two sides of each face of the cube. There are two similar grooves around the cube—one through the centres of the top, side, and bottom faces; the other through the centres of the front, side, and back faces. $x=1\frac{1}{2}''$, $y=1\frac{1}{2}''$.

NOTES—PLATE III

Before beginning the plate, study Arts. 54 and 55.

x and y are given for figures which extend to the right of the point located (Art. 54 *b*).

Begin Figs. 2 (*a*) and 2 (*b*) by drawing a 45° line from the point located. The centres of all circles or hexagons will be on this line. (Why?)

Begin all figures in which there are grooves or raised strips by drawing the object first, subsequently cutting out the grooves or adding the strips. Omit lines where raised strips intersect each other except those lines which are necessary to show the corners.

Shade the edges which cast shadows, as in isometric. In 2 (*a*) shade the lower right-hand quadrant of front circles (see Art. 36 *b*). This figure may also be improved by shading with parallel lines to make the surfaces appear cylindrical (Art. 37).

OPTIONAL III

1. Draw a rectangle about 2″ wide and 5″ high, and shade it with line-shading to represent a vertical cylinder. See Art. 37.
2. Shade a rectangle 2″ high by 5″ long to represent a horizontal cylinder.

PLATE IV*

ISOMETRIC AND CABINET PROJECTION

1 (*a*). Make an isometric drawing of the frustum of a cone; the lower base is 3″ in diameter, the upper base 2″ in diameter; the height of the frustum (perpendicular distance between the two bases) is 3″. Use the isometric scale. $x=5\frac{1}{4}''$, $y=1\frac{3}{16}''$ (to corner of square in which base is inscribed).

1 (*b*). Make an isometric drawing of two cylinders, one on top of the other. The lower cylinder stands on a base 3″ in diameter and is 2″ high; in the centre of its upper base stands a second cylinder 2″ in diameter and 1″ high. Use the isometric scale. $x=5\frac{1}{4}''$, $y=1\frac{3}{16}''$ (to corner of square in which base is inscribed).

2 (*a*). Make a cabinet drawing of the frustum of 1 (*a*). $x=3\frac{1}{4}''$, $y=1\frac{9}{16}''$ (to corner of square in which the base is inscribed).

2 (*b*). Make a cabinet drawing of the cylinders of 1 (*b*). $x=3\frac{1}{4}''$, $y=1\frac{9}{16}''$ (to corner of square in which the base is inscribed).

3 (*a*). Make an isometric drawing to isometric scale of a 3″ cube; in the centre of each face there is a circular hole 2″ in diameter by $\frac{1}{4}''$ deep. $x=5\frac{1}{4}''$, $y=1\frac{1}{16}''$.

3 (*b*). Make an isometric drawing to isometric scale of a 3″ cube; in the centre of each face there is a raised circular block 2″ in diameter by $\frac{1}{4}''$ thick. $x=5\frac{1}{4}''$, $y=1\frac{1}{16}''$.

4 (*a*). Make a cabinet drawing of the cube of 3 (*a*). $x=3\frac{3}{16}''$, $y=1\frac{7}{16}''$.

4 (*b*). Make a cabinet drawing of the cube of 3 (*b*). $x=3\frac{3}{16}''$, $y=1\frac{7}{16}''$.

NOTES—PLATE IV

Study Arts. 49, 50, 51, 56, 57, and 58.

Every figure in this plate contains circles which project into ellipses. Draw the circumscribed square in each case, except in 3 (*a*) and 4 (*a*), where the part of the inner ellipse which shows can be made most easily by shifting the outer ellipse parallel to itself.

A good comparison of the two projections is afforded by this plate. Either may be advantageously used to represent objects to persons not skilled in reading ordinary working drawings. So-called "show drawings" (as compared to *working drawings*) are therefore often made in one of these two projections.

OPTIONAL IV

Make a cabinet drawing of one of the objects given in Optional II.

Any similar object approved by the instructor may be chosen instead.

* In abridged courses this plate may be given as an optional.

PLATE V

ORTHOGRAPHIC PROJECTION ILLUSTRATED BY ISOMETRIC PROJECTION

Represent by means of isometric projection the following point and lines, together with the top view and front view of each on H and V respectively:

1 (*a*). A point 1 in space 1″ behind V and 2″ below H. (Notes *a* and *b*.)

1 (*b*). A point 1 in space 2″ behind V and 1″ below H. (Notes *a* and *b*.)

2 (*a*). A straight line $\overline{2\text{–}3}$ $2\frac{1}{2}''$ long, perpendicular to H and 1″ behind V. One end of the line is in H. (Note *d*.)

2 (*b*). A straight line $\overline{2\text{–}3}$ 2″ long, perpendicular to H and $1\frac{1}{4}''$ behind V. The upper end of the line is $\frac{1}{2}''$ below H.

3 (*a*). A straight line $\overline{4\text{–}5}$ 2″ long, perpendicular to V and $1\frac{1}{4}''$ below H. The nearer end of the line is $\frac{1}{2}''$ behind V.

3 (*b*). A straight line $\overline{4\text{–}5}$ $2\frac{1}{2}''$ long, perpendicular to V and 1″ below H. One end of the line is in V. (Note *d*.)

Draw the top view and front view in true orthographic projection of:

4 (*a*). The point 1 of 1 (*a*). (Note *c*.)

4 (*b*). The point 1 of 1 (*b*). (Note *c*.)

5 (*a*). The line $\overline{2\text{–}3}$ of 2 (*a*).

5 (*b*). The line $\overline{2\text{–}3}$ of 2 (*b*).

6 (*a*). The line $\overline{4\text{–}5}$ of 3 (*a*).

6 (*b*). The line $\overline{4\text{–}5}$ of 3 (*b*).

NOTES—PLATE V

Study Arts. 59–69 (*d*) inclusive.

Draw a border line 21″ × 14″ and divide the enclosed space into six 7″ squares, one for each problem. Draw the first three problems in the upper row. Place (4) under (1), (5) under (2), and (6) under (3).

Commence each of the first three problems by drawing the three *isometric axes* from the centre of the 7″ square, the *vertical axis* extending downward. Make the *axes* each 3″ long, and construct upon them two planes corresponding to the *top* and the *left-hand front* faces of an *isometric cube*. Let these planes represent a portion of the two planes of *orthographic projection* (which are in reality of infinite extent), forming together the *third angle of projection*. The given point or line is located in this *angle* according to the conditions of the problem, and its *views* are then drawn on the two planes which represent the *planes of projection*.

The problems of this and the succeeding four plates are given mainly to illustrate the fundamental principles of *orthographic projection*. They are first drawn in *isometric* or *cabinet projection*, as the case may be, because it is thought that in this way the true

conception of the principles above referred to is more easily and quickly attained. Incidentally further practice is also gained in the *isometric* and *cabinet projections.*

At first it is easier to imagine the point, line, or object itself located in the angle between the two *planes of projection*—the *views* upon those planes will then follow. The first three problems of each of the five plates before mentioned will aid the imagination in this. Eventually, however, the student will become accustomed to *projection* pure and simple, and will not need to go through this mental process. See Art. 64 (*d*).

Special Notes

(*a*) Mark the two *planes of projection* Horizontal Plane and Vertical Plane respectively, and their line of intersection Ground Line. Mark the *top view* and *front view* of the point 1, 1h and 1v respectively. Indicate that they are *views* of 1 by drawing two lines (of very *fine short dashes*) to 1. The middle portion of each of these *projecting lines* may be omitted, only about $\frac{1}{2}''$ of each end being drawn. Ink in the *ground line* at least twice as heavy as any other line on the plate. Make the edges of the planes lighter than the other lines (projecting lines excepted). All similar lines on the plate should be of a uniform width. Ink in the given point or line with red ink. All other lines, including the *views* on the planes, are black. Follow the above directions in the two succeeding plates also.

(*b*) Arrange the given point and lines in the first three problems as symmetrically as possible with respect to the edges of the planes, without conflicting with the given conditions.

(*c*) Arrange each of the last three problems in the centre of its square, making the *ground line* 3 in. long. Do not draw the outline of the planes of projection, simply the ground line.

(*d*) If 2 is the end of the line $\overline{2-3}$ in H, then 2 coincides with 2h and 3h. Mark this point, which is also the *top view* of *every* point in the line $\overline{2-3}$, thus: 2 and $\overline{2-3}$h.

OPTIONAL V

1. Isometric drawing of a plain brick arch fireplace or similar object having a cylindrical surface.

2. Cabinet drawing of the same object. Place the object so that the circles will be represented by ellipses.

PLATE VI

ORTHOGRAPHIC PROJECTION ILLUSTRATED BY ISOMETRIC PROJECTION

Represent by means of isometric projection the following lines, together with the top view and front view of each on H and V respectively:

1 (*a*). A straight line $\overline{1-2}$ $2\frac{1}{2}''$ long, parallel to both H and V, $2''$ below H and $1\frac{1}{2}''$ behind V.

1 (*b*). A straight line $\overline{1-2}$ $2\frac{1}{2}''$ long, parallel to both H and V, $1\frac{1}{2}''$ below H and $2''$ behind V.

2 (*a*). A straight line $\overline{3-4}$ $2\frac{7}{8}''$ long, which makes an angle of 60° with H, is parallel to and $1\frac{1}{2}''$ behind V. The upper end of the line is $\frac{3}{8}''$ below H.

2 (*b*). A straight line $\overline{3-4}$ $3''$ long, which makes an angle of 60° with H, is parallel to and $1\frac{1}{2}''$ behind V. The upper end of the line is in H.

3 (*a*). A straight line $\overline{5-6}$ $3''$ long, which makes an angle of 60° with V, is parallel to and $1\frac{1}{2}''$ below H. The nearer end of the line is in V.

3 (*b*). A straight line $\overline{5-6}$ $2\frac{7}{8}''$ long, which makes an angle of 60° with V, is parallel to and $1\frac{3}{4}''$ below H. The nearer end of the line is $\frac{3}{8}''$ behind V.

Draw the top view and front view in true orthographic projection of:

4 (*a*). The line $\overline{1-2}$ of 1 (*a*).

4 (*b*). The line $\overline{1-2}$ of 1 (*b*).

5 (*a*). The line $\overline{3-4}$ of 2 (*a*).

5 (*b*). The line $\overline{3-4}$ of 2 (*b*).

6 (*a*). The line $\overline{5-6}$ of 3 (*a*).

6 (*b*). The line $\overline{5-6}$ of 3 (*b*).

NOTES—PLATE VI

Study Arts. 70–71.

The general arrangement of the figures of this plate is similar to that of the previous plate. There are only three red lines on the plate—the given line in each of the first three problems.

OPTIONAL VI

Describe how to find the axes of the ellipses which represent circles inscribed in the top and side faces of a cube in cabinet projection, and illustrate by a drawing. See Art. 56 (*b*).

PLATE VII*

ORTHOGRAPHIC AND CABINET PROJECTIONS

1 (*a*). The top view of a line $\overline{1-2}$ is $2\frac{3}{4}''$ long and makes an angle of 45° with the ground line, the nearer end being $\frac{1}{2}''$ behind the ground line; the front view of the same line makes an angle of 30° with the ground line, the nearer end being $\frac{1}{2}''$ below the ground line. Find by means of orthographic projection the true length of the line $\overline{1-2}$.

1 (*b*). Same as 1 (*a*), except the top view of the line makes an angle of 30°

* See Arts. 73 and 74. In abridged courses this plate may be given as an optional.

with the ground line, while the angle which the front view makes with the ground line is 45°. Length of the top view $2\frac{3}{4}''$.

2 (*a*). A line $\overline{3\text{–}4}$ is $2\frac{3}{4}''$ long. Find its views on H and V in true orthographic projection when the line itself makes an angle of 30° with H and of 45° with V.

2 (*b*). Same as 2 (*a*), except that the line itself makes an angle of 45° with H and of 30° with V.

Illustrate by means of cabinet projection the methods used in:

3 (*a*). Problem 1 (*a*).

3 (*b*). Problem 1 (*b*).

4 (*a*). Problem 2 (*a*).

4 (*b*). Problem 2 (*b*).

OPTIONAL VII

If a line makes an angle of x° with V and y° with H, and $x^\circ + y^\circ = 90^\circ$, what angle will the plane in which the line lies make with H and V? Illustrate by a drawing.

PLATE VIII

ORTHOGRAPHIC PROJECTION ILLUSTRATED BY CABINET PROJECTION

Represent by means of cabinet projection the following solids, together with their top and front views on H and V respectively:

1 (*a*). A square prism $2\frac{1}{2}''$ high; side of base $1\frac{1}{2}''$ long. The plane of the upper base is parallel to and $\frac{3}{4}''$ below H. The plane of one side face makes an angle of 15° with V. The centre of the prism is 2″ behind V. Let the nearest edge to V be a left-hand edge. (Note *a*.)

1 (*b*). The prism of 1 (*a*) when one face is parallel to and $1\frac{1}{4}''$ behind V. The plane of the upper base is parallel to and $\frac{3}{4}''$ below H.

2 (*a*). A hexagonal pyramid $2\frac{1}{2}''$ high; side of base 1″ long; vertex over the centre of the base, 2″ behind V. The plane of the base is parallel to and $3\frac{1}{4}''$ below H; two sides of the base are parallel to V. (Note *b*.)

2 (*b*). The pyramid of 2 (*a*) in the same position, except no side of the base is parallel or perpendicular to V. (Note *b*.)

3 (*a*). The prism of 1 (*a*) when the plane of a $2\frac{1}{2}'' \times 1\frac{1}{2}''$ face is parallel to and $1\frac{1}{4}''$ below H, while another similar face is parallel to and $1\frac{1}{4}''$ behind V. Show, in addition, an end view assuming the nearer end of the prism $\frac{5}{8}''$ from the end plane.

3 (*b*). A cylinder $2\frac{1}{2}''$ long and $1\frac{1}{2}''$ in diameter, when the axis of the cylinder is parallel to and 2″ from both H and V. Show, in addition, an end view assuming the nearer end of the cylinder $\frac{5}{8}''$ from the end plane.

Draw the top and front views in true orthographic projection of:

4 (*a*). The prism of 1 (*a*).

4 (*b*). The prism of 1 (*b*).

5 (*a*). The pyramid of 2 (*a*).

5 (*b*). The pyramid of 2 (*b*).

6 (*a*). The prism of 3 (*a*). Draw also an end view. (Note *c*.)

6 (*b*). The cylinder of 3 (*b*). Draw also an end view. (Note *c*.)

NOTES—PLATE VIII

Study Arts. 76 to 84 inclusive.

From a point $4\frac{3}{4}''$ from both the lower and left-hand edges of each of the three upper squares, draw the three axes of cabinet projection. Construct upon these axes planes corresponding to the top and front faces of a $3\frac{3}{4}''$ cube, and let these planes represent respectively H and V. First draw the solid itself in the angle thus formed, and then the top and front views of it on the planes representing H and V.

The lines of the solid itself in each of the first three problems are drawn with red ink. All other lines on the plate, including those which represent the different views of the solids on the planes, are black. In orthographic projection certain edges are drawn heavier than others (Art. 128).

Invisible edges are to be shown by broken lines of long dashes close together. Construction lines and projecting lines are very short, fine dashes (Arts. 32 *a*, 32 *b*).

The ground line for each of the problems in true orthographic is $3\frac{3}{4}''$ long, and is drawn $3\frac{3}{4}''$ above the lower border line.

Draw portions of each projecting line, and number corresponding points and views as 2, 2h, and 2v in each problem.

(*a*) Before starting the top view, 1 (*a*), in cabinet projection, draw in pencil the top view of 4 (*a*) in its proper place on the plate. This view will be a $1\frac{1}{2}''$ square, with one side at an angle of 15° with the ground line; use the perpendiculars from ground line to the corners of this square as co-ordinates to find top view, 1 (*a*) (Art. 48 *b*). Whenever views cannot be drawn directly in cabinet or isometric projection, it will be found necessary to resort to a similar method of drawing a view in true orthographic projection first.

(*b*) A common error is to forget to ink in the edges of the pyramid in the top view, 2 (*a*), 2 (*b*), 5 (*a*), 5 (*b*). These edges, of course, are visible.

(*c*) The clear space between the front and end views, 6 (*a*), 6 (*b*), is $1\frac{7}{8}''$. (Why?) This makes it necessary to begin the front view $\frac{9}{16}''$ from the left-hand side of the square.

OPTIONAL VIII

1. Find the true shape and size of a triangular face of the pyramid of 2 (*a*), Plate VIII. Indicate clearly the method by broken lines in the drawing.

2. Draw the top and front views of a hexagonal pyramid, a face of which is bounded by two sides, true length $3\frac{1}{2}''$, and a third side $1\frac{1}{2}''$ long.

NOTE.—No arithmetical calculation to be used in either problem.

PLATE IX

ORTHOGRAPHIC PROJECTION ILLUSTRATED BY CABINET PROJECTION

Given an octagonal pyramid $2\frac{1}{2}''$ high; side of octagon $=\frac{3}{4}''$. Represent by means of cabinet projection this pyramid, together with its top and front views on H and V respectively, in each of the following positions:

1 (*a*). When the plane of the base is parallel to and $3''$ below H. Vertex above the base.

1 (*b*). The same problem as 1 (*a*), substituting a heptagonal pyramid for the octagonal one of 1 (*a*). The heptagon can be inscribed in a circle $2''$ in diameter.

2 (*a*). When the plane of the base is parallel to and $3''$ behind V. Vertex in front of the base.

2 (*b*). The same problem as 2 (*a*), substituting the heptagonal pyramid of 1 (*b*) for the octagonal pyramid.

3 (*a*). When the plane of the base is parallel to and $\frac{1}{2}''$ below H. Vertex below the base.

3 (*b*). The same problem as 3 (*a*), substituting the heptagonal for the octagonal pyramid.

4 (*a*). When the plane of the base is parallel to and $\frac{1}{2}''$ behind V. Vertex behind the base.

4 (*b*). The same problem as 4 (*a*), substituting the heptagonal for the octagonal pyramid.

Draw the top and front views in true orthographic projection of:

5 (*a*). The pyramid of 1 (*a*).
5 (*b*). The pyramid of 1 (*b*).
6 (*a*). The pyramid of 2 (*a*).
6 (*b*). The pyramid of 2 (*b*).
7 (*a*). The pyramid of 3 (*a*).
7 (*b*). The pyramid of 3 (*b*).
8 (*a*). The pyramid of 4 (*a*).
8 (*b*). The pyramid of 4 (*b*).

NOTES—PLATE IX

In the first four problems make the planes of projection equal to the corresponding faces of a $3\frac{1}{2}''$ cube. $x=\frac{3}{8}''$, $y=1\frac{1}{8}''$. The axes of the pyramids are all $1\frac{3}{4}''$ from the planes to which they are parallel.

Show all invisible edges unless they fall behind full lines.

Draw the solids in red ink.

Omit projecting lines and numbers in the true orthographic figures. Make ground line $7''$ long, $3\frac{1}{2}''$ above bottom border line.

OPTIONAL IX

Make a working drawing of 1 (*a*), Optional II. Give all necessary information and dimensions. See Chapter VIII. Show invisible edges by broken lines.

PLATE X

ORTHOGRAPHIC PROJECTION ILLUSTRATED BY ISOMETRIC PROJECTION

Represent by means of isometric projection the following solids, together with the top, front, and end views of each on three planes of projection.

1 (*a*). A hexagonal prism $2\frac{1}{2}''$ long; side of hexagon $\frac{3}{4}''$ long. The axis of the prism is parallel to and $1\frac{1}{2}''$ from both H and V. The planes of two faces of the prism are each perpendicular to H.

1 (*b*). The same problem as 1 (*a*), except the planes of two faces of the prism are each perpendicular to V.

2 (*a*). A prism $1\frac{1}{2}''$ square and $2\frac{1}{2}''$ long. The axis of the prism is parallel to and $1\frac{1}{2}''$ from both H and V. Two faces of the prism are parallel to H. Through the centre of the prism, running lengthwise from end to end, there is a circular hole $1''$ in diameter.

2 (*b*). A cylinder $1\frac{1}{2}''$ in diameter and $2\frac{1}{2}''$ long. The axis of the cylinder is parallel to and $1\frac{1}{2}''$ from both H and V. Through the centre of the cylinder, running lengthwise from end to end, there is a hole $\frac{3}{4}''$ square. Two sides of the hole are parallel to H.

Draw the top, front, and end views in true orthographic projection of:

3 (*a*). The prism of 1 (*a*).
3 (*b*). The prism of 1 (*b*).
4 (*a*). The prism of 2 (*a*).
4 (*b*). The cylinder of 2 (*b*).

NOTES—PLATE X

In the first two figures make the planes of projection equal to the corresponding faces of a 3″ cube. Draw the solids in red ink.

Draw end views in true orthographic projection before drawing the problems in isometric projection.

Show the hole in top and front views [2 (*a*), 2 (*b*), 4 (*a*), 4 (*b*)] by broken lines.

OPTIONAL X

Make a working drawing of 1 (*c*), Optional II.

PLATE XI

ORTHOGRAPHIC PROJECTION

Draw the top, front, and side views in true orthographic projection of:

1 (*a*). A hexagonal prism 3″ high; side of hexagon 1″ long. The plane of the upper base is parallel to and ¼″ below H. No side face is parallel or perpendicular to V.

1 (*b*). A hexagonal pyramid 3″ high; side of hexagon 1″ long. The plane of the base is parallel to and 3¼″ below H. No side of the base is parallel or perpendicular to V. Vertex is above the base.

2 (*a*). A semi-cylinder, the front half of the original cylinder having been removed. The plane of the upper base is parallel to and ¼″ below H. The radius of the base is 1″; the height of the semi-cylinder is 3″.

2 (*b*). A semi-cone, the front half of the original cone having been removed. The plane of the base is parallel to and 3¼″ below H. The radius of the base is 1″; the distance of the vertex above the base is 3″.

3 (*a*). The frustum of the pyramid of 1 (*b*) when the pyramid is cut off by a plane parallel to and 2″ above the base; pyramid in the same position as in 1 (*b*).

3 (*b*). A prism 1¾″ square and 3″ high, having its upper base parallel to and ¼″ below H. Two side faces are perpendicular to V. In each of these side faces are two grooves, the centre lines of which correspond to the diagonals of the face. Grooves are ⅜″ wide and ¼″ deep.

4 (*a*). The frustum of the semi-cone of 2 (*b*) when the semi-cone is cut off by a plane parallel to and 2″ above the base; semi-cone in the same position as in 2 (*b*).

4 (*b*). Three semi-cylinders, A, B, and C, the front half of each of the original cylinders having been removed. Each semi-cylinder is 1″ high, and their radii are: for A 1¼″, for B ⅞″, and for C ½″. C rests upon B, B upon A, and the plane of the base of A is parallel to and 3¼″ below H. The axes of all three cylinders are in the same straight line perpendicular to H.

NOTES—PLATE XI

Let the solid in each problem be any convenient distance behind V.

Show all invisible edges. The 2″ is the perpendicular, not the slant height [3 (*a*), 4 (*a*)]. The top view of the upper base of the frustum is obtained from the front view.

OPTIONAL XI

Make a working drawing of 1 (*b*), Optional II.

PLATE XII

ORTHOGRAPHIC PROJECTION

Draw the top and front views in orthographic projection of the following solids described in previous plates:

1 (*a*). The blocks of 3 (*a*), Plate II.
1 (*b*). The blocks of 3 (*b*), Plate II.
2 (*a*). The cube of 4 (*a*), Plate II.
2 (*b*). The prism of 4 (*b*), Plate II.
3 (*a*). The solid of 5 (*a*), Plate II.*
3 (*b*). The cube of 5 (*b*), Plate II.*
4 (*a*). The cylinders of 2 (*a*), Plate III.*
4 (*b*). The prisms of 2 (*b*), Plate III.*
5 (*a*). The block of 4 (*a*), Plate III.*
5 (*b*). The block of 4 (*b*), Plate III.*
6 (*a*). The cube of 6 (*a*), Plate III.*
6 (*b*). The cube of 6 (*b*), Plate III.*

* Problems marked * are to be drawn three-fourths full size; the other four problems are to be drawn full size. Arrange each problem in the centre of its square and omit ground lines. Choose the simplest position for each solid.

OPTIONAL XII

Make a working drawing of a carpenter's bench.

PLATE XIII

ORTHOGRAPHIC PROJECTION ILLUSTRATED BY CABINET PROJECTION

Given a prism 3″ high and $1\frac{1}{2}$″ square. Represent by means of cabinet projection this square prism, together with its top and front views on H and V respectively when the prism is in the following positions:

1 (*a*). When the plane of the upper square base is parallel to and $\frac{1}{2}$″ below H; centre of base $1\frac{1}{2}$″ behind V. The plane of a side face makes an angle of 30° with V.

1 (*b*). When the plane of the front square base is parallel to and $\frac{3}{8}$″ behind V; centre of base 2″ below H. The plane of a side face makes an angle of 30° with H.

2 (*a*). Keeping the prism in the same position with respect to V that it is in in 1 (*a*), tip it up until the plane of the base makes an angle of 30° with H.

2 (*b*). Keeping the prism in the same position with respect to H that it is in in 1 (*b*), tip it around until the plane of the base makes an angle of 30° with V.

3 (*a*). Keeping the prism in the same position with respect to H that it finally is in in 2 (*a*), revolve it until the top view of one of its longest edges makes an angle of 30° with the ground line.

3 (*b*). Keeping the prism in the same position with respect to V that it finally is in in 2 (*b*), revolve it until the front view of one of its longest edges makes an angle of 30° with the ground line.

Draw the top and front views in true orthographic projection of:

4 (*a*). The prism of 1 (*a*).
4 (*b*). The prism of 1 (*b*).
5 (*a*). The prism of 2 (*a*).
5 (*b*). The prism of 2 (*b*).
6 (*a*). The prism of 3 (*a*).
6 (*b*). The prism of 3 (*b*).

NOTES—PLATE XIII

Study Art. 85.

For 4 (*a*), 5 (*a*), and 6 (*a*) the ground line is 4″ above the lower border line; for 4 (*b*), 5 (*b*), and 6 (*b*) it is 3″.

In this plate draw the lower row or the last three problems first. The top views and front views thus obtained are then transferred to the cabinet planes of projection in the usual manner. These cabinet planes of projection correspond to the top and front faces of a 4″ cube. Ink in a solid red, its views black. Ink in all construction and projecting lines, omitting, however, the centre portions in most cases. Show all invisible lines.

OPTIONAL XIII

Draw a ground plan of a house. Draw a second-story plan, also, if time permits.

PLATE XIV

ORTHOGRAPHIC PROJECTION

Draw the top and front views in orthographic projection of:

1 (*a*). A pentagonal prism $2\frac{3}{4}$″ high; size of pentagon such that it can be inscribed in a 2″ circle. The upper base is in H, with its centre 2″ behind the ground line.

1 (*b*). A pentagonal pyramid 3″ high; size of pentagon such that it can be inscribed in a 2″ circle. The vertex of the pyramid is in H; plane of base parallel to H; axis of pyramid 2″ behind V.

2 (*a*). Keeping the prism in the same position with respect to V that it is in in 1 (*a*), tip it up until the plane of the base makes an angle of 30° with H.

2 (*b*). Keeping the pyramid in the same position with respect to V that it is in in 1 (*b*), tip it up until the plane of the base makes an angle of 30° with H.

3 (*a*). Keeping the prism in the same position with respect to H that it finally is in in 2 (*a*), revolve it until the top view of one of its longest edges makes an angle of 30° with the ground line.

3 (*b*). Keeping the pyramid in the same position with respect to H that it finally is in in 2 (*b*), revolve it until the top view of its axis makes an angle of 30° with the ground line.

4 (*a*). The frustum of a hexagonal pyramid; side of lower base $1\frac{1}{2}$″ long; side of upper base 1″ long; perpendicular distance between the two bases is $\frac{3}{4}$″. Plane of the lower base is parallel to and $2\frac{3}{8}$″ below H. On the centre of the upper base rests a sphere $1\frac{1}{2}$″ in diameter.

4 (*b*). The blocks of 3 (*a*), Plate II., when the common axis of the three blocks is perpendicular to V, $1\frac{1}{2}$″ below H. The plane of the nearest base is parallel to and $\frac{1}{4}$″ behind V; two of its sides are parallel to H.

5 (*a*). Keeping the two solids in the same position with respect to V that

they are in in 4 (*a*), tip them until the plane of a base of the frustum makes an angle of 45° with H.

5 (*b*). Keeping the blocks in the same position with respect to H that they are in in 4 (*b*), revolve them until the common axis makes an angle of 45° with V.

6 (*a*). Keeping the two solids in the same position with respect to H that they are in in 5 (*a*), revolve them until the top view of the line through the centres of the sphere and the hexagonal bases makes an angle of 45° with the ground line.

6 (*b*). Keeping the blocks in the same position with respect to V that they finally are in in 5 (*b*), tip them down until the projection of the common axis on V makes an angle of 15° with the ground line.

NOTES—PLATE XIV

Ground lines are in centre of rectangles for all problems except 4 (*b*), 5 (*b*), and 6 (*b*). For these problems ground lines are 3″ from lower border line.

OPTIONAL XIV

A bridge pier is 12′–0″ high, 5′–0″ × 20′–0″ on top, and has a slope on all sides of one in twelve. It is set on a skew of 30° with the roadway of the bridge. Show the top and front views of this pier when V is assumed at right angles to the roadway of the bridge.

PLATE XV

CURVES

Construct an ellipse whose major and minor axes are respectively 4″ and 2½″ long.

1 (*a*). When the major axis is horizontal.

1 (*b*). When the major axis is vertical.

Given a horizontal line 6″ long. Through the two extremities of this line and a third point construct a parabola.

2 (*a*). When the third point is 2″ above the centre of the 6″ line.

2 (*b*). When the third point is 2″ below the centre of the 6″ line.

3 (*a*). Draw two 45° lines each 6″ long, bisecting each other at right angles in a point *c*. In the upper and lower angles thus formed construct a hyperbola, one branch in each angle, using a different method for each branch. Assume the vertices on a vertical line through *c*, the vertex of the upper branch 1″ above *c*, the vertex of the lower branch 1″ below *c*.

3 (*b*). The same problem as 3 (*a*), except the branches of the hyperbola are drawn in the right and left hand angles respectively instead of the upper and lower angles. The vertices are on a horizontal line through *c*, 1″ each side of *c*.

Draw the top and front views in orthographic projection of:

4 (*a*). A cone 3⅝″ high; diameter of base 2½″. The plane of the base is parallel to and 3¾″ below H. The axis of the cone is perpendicular to H and 1½″ behind V; vertex above the base.

4 (*b*). The cone of 1 (*a*) when the plane of the base is parallel to and 3¾″ behind V. The axis of the cone is perpendicular to V and 1½″ below H; vertex in front of the base.

5 (*a*). Keeping the cone in the same position with respect to V that it is in in 4 (*a*), tip it until the plane of the base makes an angle of 30° with H.

5 (*b*). Keeping the cone in the same position with respect to H that it is in in 4 (*b*), revolve it until the plane of the base makes an angle of 30° with V.

6 (*a*). Keeping the cone in the same position with respect to H that it finally is in in 5 (*a*), revolve it until the projection of its axis on H makes an angle of 45° with the ground line.

6 (*b*). Keeping the cone in the same position with respect to V that it finally is in in 5 (*b*), tip it until the projection of its axis on V makes an angle of 45° with the ground line.

NOTES—PLATE XV

See Art. 45 for methods for drawing the curves.

The ground lines for 4 (*a*), 5 (*a*), and 6 (*a*) are 4″ from the lower border line; for 4 (*b*), 5 (*b*), and 6 (*b*) 3″ from lower border line.

Use two methods for 3 (*a*) or 3 (*b*.) Ink in all curves with the curve ruler (Art. 22), except the ellipse in 5 (*a*) and 5 (*b*) and the larger ellipse in 6 (*a*) and 6 (*b*). These ellipses may be drawn with the compasses according to Art. 45.

Ink in all axes in the upper row of figures, with a short dash and a long dash alternating (Art. 32 *c*).

For method of finding axes of ellipses in 5 (*a*), 5 (*b*), 6 (*a*), and 6 (*b*), see Art. 87. Ink in the invisible portions of the ellipses in these figures.

OPTIONAL XV

Draw the top and front views of the cube of 4 (*a*), Plate II., in one of the most complicated positions with respect to H and V in which it can be placed —*i. e.*, no face parallel to H or V.

PLATE XVI

PLANE SECTIONS

Represent by means of isometric projection the following solids, together with their top and front views on H and V respectively.

1 (*a*). A cylinder $2\frac{1}{2}''$ high; $1\frac{5}{8}''$ in diameter. The plane of the upper base is parallel to and $\frac{1}{4}''$ below H. The axis of the cylinder is $1\frac{1}{2}''$ behind V. The cylinder is cut by a plane parallel to V, $\frac{3}{8}''$ in front of the axis, and the part of the cylinder in front of the plane is removed.

1 (*b*). A hexagonal prism $2\frac{1}{2}''$ high; side of hexagon $\frac{13}{16}''$ long. The plane of the base is parallel to and $\frac{1}{4}''$ below H. The axis of the prism is $1\frac{1}{2}''$ behind V. The prism is cut by a plane parallel to V, $\frac{1}{2}''$ in front of the axis, and the part of the prism in front of the plane is removed.

2 (*a*). The cylinder of 1 (*a*) when its axis is parallel to and $1\frac{1}{2}''$ from both H and V. The cylinder is cut by a plane parallel to V, $\frac{3}{8}''$ in front of the axis, and the part of the cylinder in front of the plane is removed. Show, also, a view on the end plane.

2 (*b*). The prism of 1 (*b*) when its axis is parallel to and $1\frac{1}{2}''$ from both H and V. The prism is cut by a plane parallel to V, $\frac{1}{2}''$ in front of the axis, and the part of the prism in front of the axis is removed. Show, also, an end view.

3 (*a*). A hexagonal pyramid $2\frac{1}{2}''$ high; side of hexagon $\frac{13}{16}''$ long; plane of base parallel to and $2\frac{3}{4}''$ below H; vertex above base, $1\frac{1}{2}''$ behind V. The pyramid is cut by a plane parallel to V, $\frac{7}{16}''$ in front of the vertex, and the portion of the pyramid in front of the plane is removed. Assume two sides of the base parallel to V.

3 (*b*). The same problem as 3 (*a*), except no side of the base of the pyramid is parallel or perpendicular to V.

Draw the top and front views in true orthographic projection of:

4 (*a*). The cylinder cut by a plane of 1 (*a*).

4 (*b*). The prism cut by a plane of 1 (*b*).

5 (*a*). The cylinder cut by a plane of 2 (*a*). Show, also, an end view.

5 (*b*). The prism cut by a plane of 2 (*b*). Show, also, an end view.

6 (*a*). The pyramid cut by a plane of 3 (*a*).

6 (*b*). The pyramid cut by a plane of 3 (*b*).

NOTES—PLATE XVI

Study Arts. 88–97.

The planes of projection correspond to the faces of a $3''$ isometric cube in 1 (*a*), 1 (*b*), 2 (*a*), 2 (*b*), 3 (*a*), 3 (*b*).

Section line the solid in red, the views in black (Art. 39).

Represent the trace of the cutting plane in each problem by a dash and dot alternating (Art. 32 *d*), except where the plane cuts the solid.

OPTIONAL XVI

Make a working drawing of 1 (*d*) or 1 (*e*), Optional II., showing, in addition to the ordinary views, a section view.

PLATE XVII

PLANE SECTIONS

Draw in orthographic projection the top and front views of:

1 (*a*). A sphere $3''$ in diameter, having its centre $1\frac{3}{4}''$ from both H and V. It is cut by a plane parallel to V, $\frac{3}{4}''$ in front of the centre of the sphere, and the portion of the sphere in front of the plane is removed.

1 (*b*). Same as 1 (*a*), except the cutting plane is parallel to H, $\frac{5}{8}''$ above the centre of the sphere, and the portion of the sphere above the plane is removed.

2 (*a*). A hollow $3''$ cube, with an open hole $1''$ square in the centre of each face. The distance between the inner and outer surfaces is $\frac{5}{16}''$. The plane of the upper face is parallel to and $\frac{1}{4}''$ below H; the plane of the front face is $\frac{1}{4}''$ behind V. The cube is cut by a plane through its centre, parallel to V.

2 (*b*). The same as 2 (*a*), except the cutting plane passes through the centre of the cube parallel to H instead of V.

3 (*a*). A cylinder $3''$ high, $2''$ in diameter; plane of lower base parallel to and $3\frac{1}{4}''$ below H; axis $1\frac{1}{2}''$ behind V. The cylinder is cut by a plane perpendicular to V, and making an angle of 45° with H. The portion of the cylinder above the cutting plane is removed. Assume the cylinder to be cut $2''$ up the axis. (Show, also, true size of section cut.)

3 (*b*). A hollow hexagonal prism $3''$ high; side of larger hexagon $1''$ long;

perpendicular distance between the inner and outer surfaces is $\frac{3}{8}''$; plane of the lower base is parallel to and $3\frac{1}{4}''$ below H; axis of the prism $1\frac{1}{2}''$ behind V. The prism is cut $2''$ up its axis by a plane perpendicular to V, and making an angle of 45° with H. The portion of the prism above the cutting plane is removed. (Show, also, true size of section cut.)

4 (*a*). A hollow hexagonal pyramid $3''$ long from base to vertex; side of larger hexagon $1''$ long; perpendicular distance between the inner and outer surfaces is $\frac{1}{4}''$; axis of the pyramid parallel to and $1\frac{1}{2}''$ from both H and V; no side of the base parallel or perpendicular to H. The pyramid is cut by a plane parallel to V and $\frac{1}{2}''$ in front of the axis. The portion of the pyramid in front of the plane is removed.

4 (*b*). The same as 4 (*a*), except the cutting plane is parallel to H and $\frac{1}{2}''$ above the axis. The portion of the pyramid above the plane is removed.

5 (*a*). The pyramid of 4 (*a*) when the plane of its base is parallel to and $3\frac{1}{4}''$ below H; axis $1\frac{1}{2}''$ behind V; no side of the base is parallel or perpendicular to V. The pyramid is cut by a plane through its axis perpendicular to H, and making an angle of 30° with V. The portion of the pyramid in front of the cutting plane is removed.

5 (*b*). The pyramid of 5 (*a*) in the same position as in 5 (*a*). The cutting plane passes through the vertex of the pyramid and intersects the plane of the base in a line parallel to V, $\frac{1}{2}''$ in front of the centre of the base. The portion of the pyramid in front of the cutting plane is removed.

6 (*a*). The sphere of 1 (*a*) in the same position as in 1 (*a*). The cutting plane is perpendicular to H and makes an angle of 30° with V. The nearest distance from the centre of the sphere to the cutting plane is $\frac{3}{4}''$.

6 (*b*). The same as 6 (*a*), except the cutting plane is perpendicular to V and makes an angle of 30° with H. The nearest distance from the centre of the sphere to the cutting plane is $\frac{3}{4}''$.

OPTIONAL XVII

A prism $2\frac{1}{2}''$ square has its base parallel to H. Find the true shape of the section cut from it by any plane (except a profile plane) at an angle with H and V.

PLATE XVIII

CONIC SECTIONS*

Given: A cone $4''$ high; diameter of base $3''$; plane of base parallel to and $4\frac{1}{2}''$ below H; vertex above the base; axis of the cone $3\frac{1}{2}''$ behind V. Draw the top and front views in orthographic projection of this cone when cut by:

1 (*a*). A plane parallel to V and $\frac{5}{8}''$ in front of the axis.

2 (*a*). A plane perpendicular to V and making an angle of 45° with H. The plane cuts the axis of the cone $1\frac{3}{4}''$ from the base. Show, also, the true shape of the section cut from the cone.

3 (*a*). A plane perpendicular to V and parallel to an extreme side element of the cone. The plane cuts the axis of the cone $2\frac{1}{4}''$ from the base. Show, also, the true shape of the section cut from the cone.

Given: A cone $4''$ high; diameter of base $3''$; plane of base parallel to and $4\frac{1}{2}''$ behind V; vertex in front of the base; axis of the cone $3\frac{1}{2}''$ below H. Draw the top and front views in orthographic projection of this cone when cut by:

1 (*b*). A plane parallel to H and $\frac{5}{8}''$ above the axis.

2 (*b*). A plane perpendicular to H and making an angle of 45° with V. The plane cuts the axis of the cone $1\frac{3}{4}''$ from the base. Show, also, the true shape of the section cut from the cone.

3 (*b*). A plane perpendicular to H and parallel to an extreme side element of the cone. The plane cuts the axis of the cone $2\frac{1}{4}''$ from the base. Show, also, the true shape of the section cut from the cone.

OPTIONAL XVIII

Draw a plate of line-shading similar to that shown on page 105.

PLATE XIX

INTERSECTION OF THE SURFACES OF SOLIDS †

Show by means of isometric projection the following solids, together with their top and front views on H and V respectively.

1 (*a*). Two intersecting cylinders whose axes bisect each other at right

* Study Arts. 98 (*a*), (*b*), (*c*).

† Study Arts. 102–104.

angles. One cylinder with its upper base in H is 2″ in diameter, the other, with its axis parallel to H and V, is $2\frac{1}{2}$″ in diameter. Each cylinder is 5″ long. The axis of the vertical cylinder is 3″ behind V. (Let H and V correspond to the top and front faces of a 6″ isometric cube.)

1 (*b*). The same problem as 1 (*a*), except the larger cylinder is vertical and the smaller cylinder horizontal.

Draw the top and front views in true orthographic projection of:

2 (*a*). The cylinders as they are in 1 (*a*).

2 (*b*). The cylinders as they are in 1 (*b*).

OPTIONAL XIX

Make out of card-board the two intersecting cylinders of Plate XIX.

PLATE XX

INTERSECTION OF THE SURFACES OF SOLIDS

Draw the top and front views in true orthographic projection of:

1 (*a*). The intersection of a sphere 4″ in diameter, with its centre $2\frac{1}{2}$″ from H and $3\frac{3}{4}$″ from V, by a cylinder 5″ high and $1\frac{1}{2}$″ in diameter. Upper base of the cylinder is in H, with its centre on a 45° line through the top view of the centre of the sphere $1\frac{1}{8}$″ from it.

1 (*b*). The same problem as 1 (*a*), substituting a hexagonal prism 5″ high, side of hexagon $\frac{3}{4}$″ long, for the cylinder given in 1 (*a*).

2 (*a*). Develop one end of the cylinder of 1 (*a*).

2 (*b*). Develop one end of the prism of 1 (*b*).

Draw the top and front views in true orthographic projection of:

3 (*a*). The intersection of a cylinder and hexagonal prism whose axes bisect each other at right angles. The cylinder is 5″ long and $2\frac{1}{2}$″ in diameter; its upper base is in H; its axis is $3\frac{1}{2}$″ behind V. The axis of the prism is parallel to both H and V; a side of the hexagon is 1″ long; length of prism 5″.

3 (*b*). Same as 3 (*a*), except the cylinder is 2″ in diameter, while the length of a side of the hexagon for the prism is $1\frac{1}{4}$″.

4 (*a*). Develop one end of the prism of 3 (*a*).

4 (*b*). Develop one end of the cylinder of 3 (*b*).

NOTES—PLATE XX

Study Arts. 105, 107 and 109, 110.

For this plate divide the space within the border line into four spaces each 14″×$5\frac{1}{4}$″.

OPTIONAL XX (to be drawn after Plate XXI)

Make out of card-board the two intersecting cylinders of 3 (*a*), Plate XXI.

PLATE XXI*

INTERSECTION OF THE SURFACES OF SOLIDS

Draw the top and front views in orthographic projection of:

1 (*a*). The intersection of a cone and a cylinder. The cone is 4″ high and the diameter of its base is 3″; the plane of its base is parallel to and $4\frac{1}{2}$″ below H; vertex above the base. The cylinder is 2″ in diameter and 4″ long. The axis of the cylinder is parallel to both H and V, and intersects the axis of the cone $1\frac{1}{4}$″ from the base of the cone.

1 (*b*). Same as 1 (*a*), except the axis of the cylinder intersects the axis of the cone $1\frac{3}{4}$″ from the base of the cone.

2 (*a*). Develop the cone of 1 (*a*).

2 (*b*). Develop the lower part of the cone of 1 (*b*).

Draw the top and front views in orthographic projection of:

3 (*a*). The intersection of a vertical by an oblique cylinder. The vertical cylinder is $2\frac{1}{2}$″ in diameter and 4″ high, with its upper base parallel to and $\frac{1}{2}$″ below H. The oblique cylinder is 4″ long and 2″ in diameter, with its axis parallel to V, but making an angle of 15° with H. The axes of the two cylinders bisect each other.

3 (*b*). The same as 3 (*a*), except the diameter of the vertical cylinder is 2″, while that of the oblique cylinder is $2\frac{1}{2}$″.

NOTES—PLATE XXI

Study Art. 106.

Divide the plate into three spaces each 14″×7″.

* This plate may be omitted in abridged courses.

OPTIONAL XXI

A $3''$ pipe passes through a hollow box $12'' \times 12'' \times 12''$. Sides of box $1''$ thick. The centre of the pipe is $4''$ from the left-hand and lower sides of the front face of the box and $4''$ from the right-hand and upper edges of the back face. Make a working-drawing of the box, showing the shape of holes in the sides for the pipe to pass through.

PLATE XXII

SHADOWS

Find the shadow cast upon H by:

1 (*a*). The square prism of 4 (*a*), Plate VIII. Assume the *lower* base in H; the front edge is $6\frac{1}{4}''$ in front of V; the right-hand side face makes an angle of 60° with V.

1 (*b*). A square prism $2\frac{1}{2}''$ high; side of base $1\frac{1}{2}''$. Base in H. Front face to and $6\frac{1}{2}''$ in front of V.

2 (*a*). The octagonal pyramid of 1 (*a*), Plate IX., when its base is parallel to and $\frac{1}{2}''$ above H; axis $5\frac{3}{8}''$ in front of V; vertex above the base.

2 (*b*). A heptagonal pyramid $2\frac{1}{2}''$ high; base inscribed in a circle $2''$ in diameter. Plane of base parallel to and $1\frac{1}{2}''$ above H. Axis $5\frac{1}{2}''$ in front of V.

3 (*a*). The semi-cylinder of 2 (*a*), Plate XI., when its lower base is in H and the axis $5\frac{1}{4}''$ in front of V.

3 (*b*). The semi-cone of 2 (*b*), Plate XI., when the base is parallel to and $1''$ above H. Axis of cone $6\frac{1}{2}''$ in front of V.

NOTES—PLATE XXII

Study Arts. 112–120, and Art. 40.

Divide the space within the border line into three $14'' \times 7''$ rectangles.

The distance from the left-hand side of the rectangle to a point in the top view is:

For Fig. 1 (*a*) about $2\frac{9}{16}''$ to the top view of the front edge of prism.
For Fig. 1 (*b*) about $1\frac{1}{2}''$ to left-hand front corner of base.
For Fig. 2 (*a*) about $2\frac{11}{16}''$ to centre of octagon.
For Fig. 2 (*b*) about $2''$ to centre of heptagon.
For Fig. 3 (*a*) about $2''$ to centre of semi-circle.
For Fig. 3 (*b*) about $2''$ to centre of semi-circle.

The ground line for each figure is $5''$ below the top of the rectangle.

Do not ink in the outline of the shadow.

Put on the tint before inking.

Shade the parts of the different views in shadow a lighter tint than that used for the shadows on H.

OPTIONAL XXII

Find the isometric shadows of the solids of 4 (*a*), Plate II., and 5 (*a*), Plate III.

PLATE XXIII

SHADOWS

Find the shadow cast upon H by:

1 (*a*). The blocks of 3 (*a*), Plate II., when the base of the lower block is in H. Assume the front side of this base parallel to and $6\frac{1}{2}''$ in front of V.

1 (*b*). A square prism $2\frac{1}{2}''$ high; side of base $1\frac{1}{2}''$. Front face parallel to and $7''$ in front of V. Plane of base makes an angle of 30° with H. The lowest edge is in H.

2 (*a*). The frustum and block of 5 (*a*), Plate II., when the lower base of the block is in H. Assume the front side of this base parallel to and $6\frac{1}{2}''$ in front of V.

2 (*b*). On the top of a $1\frac{1}{4}''$ cube is a block $1\frac{1}{4}''$ wide, $1\frac{1}{4}''$ high, $3\frac{1}{4}''$ long. The centre of the block is over the centre of the cube. The plane of the left-hand front faces of block and cube makes an angle of 30° with V. The front edge of block is $7''$ in front of V. Base of cube in H.

3 (*a*). Same as 3 (*b*) below, substituting cylinder $2''$ and $1''$ in diameter respectively for the corresponding hexagonal prisms. Front face of square block $6\frac{1}{2}''$ in front of V.

3 (*b*). In the centre of the upper face of a block $4''$ square and $\frac{1}{2}''$ high stands a hexagonal prism $1''$ high, with two faces perpendicular to V. Length of side $1''$. In the centre of the upper base of this prism stands a second hexagonal prism $1\frac{1}{2}''$ high, with two sides perpendicular to V; length of side $\frac{1}{2}''$. The front face of the square block is parallel to and $7''$ in front of V. Base of square block in H.

NOTES—PLATE XXIII

The ground lines and the spaces for the figures are the same as for the preceding

plate. The distance from the left-hand side of a rectangle to a point in the top view of the corresponding figure is:

For Fig. 1 (*a*) about 1″ to left-hand front corner of lowest block.
For Fig. 1 (*b*) about $2\frac{3}{8}$″ to lowest corner, *front view*.
For Fig. 2 (*a*) about $\frac{1}{16}$″ to left-hand front corner of lower block.
For Fig. 2 (*b*) about $3\frac{1}{4}$″ to front corner of upper block.
For Fig. 3 (*a*) about $\frac{7}{8}$″ to left-hand front corner of square block.
For Fig. 3 (*b*) about $\frac{13}{16}$″ to left-hand front corner of square block.

In 3 (*a*) and 3 (*b*) the shadow of the middle solid falls upon the upper face of the square block instead of on H.

OPTIONAL XXIII

1. A vertical cylinder $2\frac{1}{2}$″ in diameter and $3\frac{1}{2}$″ high stands with its base in H. Tint the shadow on H and shade the cylinder by the graded tints. See Art. 41. Let the cylinder be such a distance from V that a small portion of its shadow falls on V.

2. Same as the above, except draw cylinder in isometric, tint isometric shadow. Shade cylinder with graded shading.

PLATE XXIV

PERSPECTIVE

Make a perspective drawing of:

1 (*a*). A $2\frac{1}{2}$″ square plate, $1\frac{1}{2}$″ square hole in centre, in picture plane, edges vertical. Two similar plates exactly behind it, with 4″ space between. $x=1\frac{1}{4}$″, $y=1\frac{1}{2}$″. (Notes *a* and *b*.)

1 (*b*). A $2\frac{1}{2}$″ × 3″ rectangular plate, with 1″ × $1\frac{1}{2}$″ hole placed symmetrically in the centre. 3″ side vertical. Place in picture plane, with two similar plates directly behind, 4″ apart. $x=1\frac{1}{4}$″, $y=1\frac{1}{4}$″. (Notes *a* and *b*.)

2 (*a*). A $3\frac{1}{2}$″ square plate with 2″ square hole in centre. It is horizontal, with one edge in the picture plane. Two others behind it, $3\frac{1}{2}$″ apart. $x=1\frac{3}{4}$″, $y=1\frac{1}{2}$″. (Note *c*.)

2 (*b*). The plate of 1 (*b*) with its plane horizontal and the 3″ edge in the picture plane. Two others behind it and $2\frac{1}{2}$″ apart. (Note *d*.)

3 (*a*). A 3″ square plate, $1\frac{1}{2}$″ square hole in centre. Perpendicular to the picture plane. One edge vertical and lies in the picture plane. Two others behind it, with 3″ space between them. $x=5\frac{3}{4}$″, $y=1$″.

3 (*b*). The plate of 1 (*b*) with 3″ edge vertical and in the picture plane. Plate perpendicular to the picture plane, with two others behind it, $2\frac{1}{2}$″ apart. $x=5\frac{1}{2}$″, $y=1$″.

4 (*a*). A $2\frac{1}{2}$″ cube, face in picture plane, edges vertical. Another cube behind this, $2\frac{1}{2}$″ space between. $x=1\frac{1}{8}$″, $y=1\frac{1}{2}$″.

4 (*b*). A square prism 3″ high, side of base 2″. 2″ × 3″ face in the picture plane, with 3″ edge vertical. Another prism exactly behind, 2″ space between. $x=1\frac{1}{2}$, $y=1\frac{1}{4}$″.

5 (*a*). A square prism $\frac{3}{4}$″ high, side of base $3\frac{1}{2}$″, with 2″ square hole in centre of square face. $3\frac{1}{2}$″ × $\frac{3}{4}$″ face in the picture plane. $\frac{3}{4}$″ edge vertical. Two others behind it, with $3\frac{1}{2}$″ space between them. $x=1\frac{3}{4}$″, $y=1\frac{1}{2}$″ (Note *e*.)

5 (*b*). Same problem as 5 (*a*), except that there is no square hole; instead, rectangular notches 2″ × $\frac{3}{4}$″ × $\frac{3}{4}$″ are cut from the edges of the block front and rear.

6 (*a*). Square pyramid 3″ high, side of base 2″. Axis vertical. One edge of base horizontal and in the picture plane. Two others behind, with bases spaced 2″ apart. $x=4$″, $y=1\frac{1}{2}$″. (Note *f*.)

6 (*b*). Square pyramid 3″ high, side of base $2\frac{1}{2}$″. Axis vertical. Base horizontal and one edge in the picture plane. Second pyramid directly behind, with $2\frac{1}{2}$″ space between. $x=3\frac{1}{4}$″, $y=1\frac{1}{2}$″. (Note *f*.)

NOTES—PLATE XXIV.

Before beginning this plate read Chapter VII., Arts. 130–140, 143.

(*a*) The first three problems have the horizon $1\frac{1}{4}$″ below border line. Take S in the middle of the horizon, and same for all three problems. S to D = 16″, and use it one-half size. Ink in visible outlines of objects heavy, construction lines in fine dots. The last three problems have horizon 1″ below the centre of the sheet. S to D = 16″, and S put in centre of the horizon.

Remember that all measurements must be made in the picture plane.

(*b*) In 1 (*a*) and 1 (*b*) the plate in the picture plane is drawn in its actual outline. The other figures appear smaller, since their corners lie on lines converging towards S.

(*c*) In 2 (*a*) draw all the $3\frac{1}{2}$″ square plates, first leaving out the square hole in the centre. Then take 2″ in the middle of the front edge and join to S. The intersection of these lines with the *diagonals* of the squares gives the 2″ square hole.

Art. 143 on equidistant spacing applies well to locating the corners of the large squares.

(*d*) In 2 (*b*) the holes, 1″ × $1\frac{1}{2}$″, in the centre of each plate must be located by measurement—$1\frac{1}{2}$″ on the front edge, 1″ on the side edge.

(*e*) 5 (*a*) is the same as 2 (*a*), except that the solid has thickness. Show the visible edges only.

(*f*) In 6 (*a*) and 6 (*b*) locate the vertex from intersection of the diagonals of the base. The height, however, must be measured in the picture plate.

OPTIONAL XXIV

A cone 4″ in diameter at base and 5″ high stands in such a position that a small portion of its shadow falls on a cylinder 3″ in diameter and 5″ high. Show all shadows, and shade the cylinder and cone with graded shading.

PLATE XXV

PERSPECTIVE

Make a perspective drawing of:

1 (*a*). The block of 3 (*a*), Plate III.
1 (*b*). The blocks of 3 (*b*), Plate II.
2 (*a*). The block of 4 (*a*), Plate III.
2 (*b*). The block of 4 (*b*), Plate III.
3 (*a*). The block and frustum of 5 (*a*), Plate III.
3 (*b*). The *two lower* blocks of 5 (*b*), Plate III.
4 (*a*). The block of 5 (*a*), Plate II.
4 (*b*). The cube of 4 (*a*), Plate II.

NOTES—PLATE XXV

The rectangle for each problem is 7″×10½″.

For 1 (*a*), 1 (*b*), 2 (*a*), and 2 (*b*) the point of sight is ¼″ below the upper border line on the line between the two upper rectangles.

For 3 (*a*), 3 (*b*), 4 (*a*), and 4 (*b*) the point of sight is 7¼″ below the upper border line on the line between the two lower rectangles.

In 1 (*b*) assume a 2″×1″ face of middle block parallel to and ¼″ behind the picture plane with a 2″ edge horizontal. This makes two vertical 1½″ edges 3½″ apart in the picture plane.

In 3 (*a*) assume a 4″×½″ face of lower block in picture plane.

In 3 (*b*) assume two faces of lower block perpendicular to picture plane with the front vertical edge of the block in the picture plane.

In 4 (*a*) assume the smaller end of the block in the picture plane.

The distance of the eye from the paper is 14″ for all problems.

1 (*a*), $x=2\frac{1}{4}''$, $y=1''$. 1 (*b*), $x=2\frac{1}{4}''$, $y=1''$ (to lower end of left-hand vertical 1½″ edge).

2 (*a*), $x=4\frac{1}{4}''$, $y=1''$. 2 (*b*), $x=4\frac{1}{4}''$, $y=1''$.

3 (*a*), $x=2\frac{1}{4}''$, $y=1''$. 3 (*b*), $x=2\frac{7}{8}''$, $y=1\frac{1}{4}''$ (to lower end of vertical edge in picture plane).

4 (*a*), $x=5\frac{3}{4}''$, $y=1\frac{1}{4}''$. 4 (*b*), $x=5\frac{3}{4}''$, $y=1\frac{1}{4}''$.

x and y are to the lower left-hand corner of face in picture plane, unless otherwise noted.

OPTIONAL XXV

Make perspective drawings of 4 (*a*), Plate XXIV., and 3 (*a*), Plate III., when no face is parallel to or in the picture plane.

PLATE XXVI

PERSPECTIVE

Make a perspective drawing of:

1 (*a*). The frustum of a cone, 1 (*a*), Plate IV.
1 (*b*). The cylinders, 1 (*b*), Plate IV.
2 (*a*). A cylinder 3″ in diameter, 3″ high. Axis vertical.
2 (*b*). A cylinder 3″ in diameter, 3″ long. Axis horizontal.
3 (*a*). The cube, 3 (*a*), Plate IV.
3 (*b*). The cube, 3 (*b*), Plate IV.

NOTES—PLATE XXVI

Study Art. 142.

Divide the plate into three 14″×7″ rectangles.

The point of sight for all problems is 5″ above the centre of the sheet, or 2″ below top of centre rectangle.

1 (*a*), $x=2''$, $y=4\frac{3}{4}''$, to left-hand front corner of square in which lower base is inscribed.

1 (*b*), $x=2''$, $y=4\frac{3}{4}''$, to left-hand front corner of square in which lowest base is inscribed.

2 (*a*) and 2 (*b*). Cylinder is directly in front of point of sight, about 5″ from lower border line. Front element in picture plane.

3 (*a*) and 3 (*b*), $x=2''$, $y=4\frac{3}{4}''$, to lower left-hand corner of face in picture plane.

Distance of eye from paper 16″ for all problems.

OPTIONAL XXVI

Make a perspective drawing of a house.

CHAPTER I

THE SELECTION OF THE OUTFIT

1. It is important that the student of drawing should have a good outfit; a poor one prevents him from doing his best work, and is a constant source of annoyance. *The beginner will be well repaid for any precautions he may take resulting in the selection of satisfactory drawing instruments and materials.**

An engineering student should be particularly careful in selecting his drawing instruments, since, with proper care, they can be used for many years.

2. It is well to purchase the outfit of some reliable dealer, where any part of it may be readily exchanged if found defective or in any way unsatisfactory. A list of instruments and materials needed by the draftsman is here given. The list is purposely made small. The draftsman can, from time to time, make such additions to this collection as are required by his work, he being better able to select wisely for himself as time goes on.

LIST OF INSTRUMENTS AND MATERIALS

1 Drawing-board (24″ × 17″).

1 Set of Drawing Instruments, including Ruling-pen, Compasses with Pen, Pencil, and Lengthening Bar, with extra HHHHHHH Leads.

1 T-square, 24″ blade (see Fig. 3, page 23).

1 45° Triangle, 9 inch (see Fig. 3).

1 30° × 60° Triangle, 11 inch (see Fig. 3).

1 12-inch Flat Scale, divided into sixteenths.

* When possible the student should intrust the selection of his outfit to a competent judge of drawing instruments and materials.

1 Semi-circular Protractor, 5 inch.

1 Curve, similar to K. & E. Rubber No. 26.

1 Drawing-pencil, HHHHHH. F – HH

Fig. 1

1 Erasing Rubber.

12 6 Thumb-tacks. Ball

1 Pen-holder, Writing-pens (Nos. 404 and 303 Gillott's), and Pen-wiper.

1 Bottle Liquid India-ink; 1 Bottle Red Drawing-ink.

1 Pencil-pointer (fine flat file or sand-paper).

White Drawing-paper (number and size of sheets depending upon the work to be done). For this course at least twenty-four sheets similar to Keuffel & Esser's "Normal Paper," 22 inches long and 15 inches wide.

The following list of materials for tinting not needed at the outset is placed here for future reference:

1 Brush, size of K. & E. No. 3121–14 or No. 7 Devoe.
½ Stick of India-ink.
1 Water-glass 2½ inches in diameter.
1 Cabinet Saucer, or Nest of Saucers, 3½ inches in diameter.
1 Small Sponge.
Paper especially adapted to tinting.

3. The Compasses.—Compasses with the needle-point leg *non-detachable*, the pen or pencil-holder forming the other leg, are preferable. This does not mean that either leg is without a joint, for such compasses, the legs of which cannot be bent (see Fig. 11, page 27), are of little value. Test the compasses for alignment by bending both legs, bringing the extremities together; they should meet perfectly. Undue effort should not be required to remove the shank of the pencil-holder from the socket, and the pen should be as easily fitted in its place. All shanks, however, should fit the sockets accurately, too loose joints being as bad as too tight ones. The needle-point should have a shoulder to prevent a large hole being made in the paper. The pen which belongs to the compasses has many points in common with the ruling-pen (see Art. 4). The best instruments are of *rolled* metal (usually German-silver), while the cheaper kind are of *cast* metal. The latter usually have a more polished or glossy finish than the former, and are easily recognized by one familiar with drawing instruments. The quality of the rolled metal cannot be determined by inspection; the reputation of the maker is the best guarantee of its excellence.

In addition to the instruments previously mentioned, the draftsman will probably need sooner or later a pair of hair-spring dividers, a pair of bow pen-compasses, a pair of bow pencil-compasses, and an extra inking-pen. When buying the instruments required at the start, it is well to have them put in a case large enough to contain these additions should they ever be made.

At present prices (1897) a pair of compasses, with attachments (pen, pencil, and lengthening bar), good enough for ordinary work, can be bought for $3.00. A first-class set of the same number of pieces costs about $7.50.

4. Ruling-pen.—It is poor economy to buy a second-class ruling-pen—a good one is absolutely necessary. A poor ruling-pen belongs in the same category with a writing-pen that scratches or a pencil which cannot be made to mark. If cheap instruments are bought, let the dealer replace the ruling-pen belonging to the set by a first-class pen. The difference in cost is not to be compared with the additional comfort to be derived from the use of a good pen. The first test of a pen is its ability to rule clear, full lines of different widths. No pen will do this unless its nibs are of even length and moderately sharp. Pens with ivory or bone handles are usually of inferior grade, and if dropped break easily. Blades ending in a rounded point are preferable to those having a narrow sharp one. The upper blade should have the thin spring back of the set-screw. The pen whose upper blade is hinged for the purpose of cleaning is going out of use. One is made, however, by Alteneder, which can be opened, cleaned, and closed again without changing the width of line; this pen is highly recommended. Its price is more than that of an ordinary pen, however, and makes it a luxury rather than a necessity.

An ordinary inking-pen of medium size costs from $1.40 to $1.90.

5. Care of Instruments.—Without proper care the best of instruments are quickly spoiled. The directions are simple—*keep them clean and dry*. *Ink should not be allowed to dry in the pen*, and all pieces should be wiped with cloth or chamois after using. It will be necessary to sharpen the pens occasionally, and every draftsman should possess a thin oil-stone for this purpose. Screw the nibs close together, and draw the pen across the stone a few times precisely as if drawing lines upon it, but changing the inclination of the pen from one side of the vertical to the other, so as to keep a rounded point. This will make the nibs of equal length, but *dull*. Unscrew the pen and sharpen each nib separately by rubbing its *outer* side on the stone, taking care to hold the pen at a *small* angle with the horizontal. The burr on the inside of the nibs may be removed by a stroke or two on the stone or with a fine flat file.

6. T-Square.—The chief requisites in a good T-square are: (1) That the blade be securely fastened to the head; (2) that the inside edge of the head be perfectly straight; (3) that the upper or ruling edge of the blade be perfectly smooth and straight, free from all nicks or rough places. The blade is more apt to remain true if the grain of the wood is parallel to the ruling edge.

A wooden T-square with a blade 24 inches long can be bought for about 25 cents. One with ebony or celluloid edges costs from 75 cents to $1.50.

7. Triangles.—Wooden triangles are usually inaccurate. Rubber or celluloid triangles are much to be preferred. Any triangle is liable to warp, but it should at least be straight when bought. Celluloid triangles warp more easily than rubber ones, but attract less dust, making it easier to keep the drawing clean. There is some advantage, also, in working with transparent triangles. On the whole, celluloid triangles are perhaps the best; they should have, however, a thickness of nearly a sixteenth of an inch, because of the tendency to warp if thin. Since the triangles are used for ruling, all edges should be smooth and straight. The right angles may be tested for accuracy by placing one side against the T-square and drawing a vertical line (see Fig. 3, page 23). Turn the triangle over, placing the same side against the T-square, and if the angle is not a right angle the vertical side will not coincide with the vertical line. Similar tests for the 45°, 30°, and 60° will suggest themselves to any one familiar with elementary principles of geometry.

Wooden triangles cost about 25 cents each. Celluloid and rubber triangles of the size recommended cost from 50 cents to 90 cents each.

8. Scale.—A 12-inch flat scale with bevel edges will answer every purpose. It will be found convenient to have one edge divided into sixteenths of an inch, the other edge into tenths of an inch. In some classes of work triangular scales are used. The usual form is the "Architect's" triangular boxwood scale, 12 inches long, with divisions $\frac{3}{32}$, $\frac{3}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{2}$, and 3 inches to the foot.

A flat scale costs about 50 cents; a triangular scale about $1.00.

9. Inks.—For a certain class of work draftsmen often prefer to make their own ink from Chinese stick-ink. For ordinary work prepared inks sold in bottles having some device in the stopper for filling the pen will answer every purpose. The ink should be absolutely black and opaque, and adhere to the paper when dry, even if rubbed over; should flow readily, dry quickly, and retain these properties for a reasonable length of time after the bottle is opened. Water-proof inks are preferable. Higgins's water-proof inks are recommended.

Cost, 25 cents per bottle.

10. Drawing-boards.—At most schools and colleges boards are loaned to the students. The ends should be straight and true to allow perfect contact with the head of the T-square. It is not necessary that the corners of the board should be exact right angles, the T-square being used on one edge of the board only. Warping should be guarded against by cleats or some other device. The top of the board should be one smooth plane.

A drawing-board 18 in. × 24 in. costs from 50 cents to 75 cents.

11. Drawing-paper.—The surface of the drawing-paper should be such that a clear, sharp ink-line of any width can be drawn upon it; it should stand a reasonable amount of erasing without being destroyed or rendered unfit for further inking. Keuffel & Esser's "Normal Paper" meets these requirements, and for ordinary work is as satisfactory as the more expensive papers.

Cost of sheets 22 in. × 15 in. about 50 cents per dozen.

12. Miscellaneous.—A curve of wood, rubber, or celluloid, similar to the one shown in Fig. 1, is recommended. Cost, from 20 cents to 45 cents. A small metal protractor, of about 2-inch outside radius, costs 50 cents. A horn protractor costs 25 cents. The pencil should be very hard (HHHHHH); cost, 10 cents. *The extra leads for the compasses should be equally hard.* A fine flat file is the best pencil-pointer. The pin of the thumb-tack should not be over $\frac{3}{16}$ in. long.

The "multiplex" erasing rubber and "Davidson's Velvet" rubber are recommended.

13. Summary: Estimated Cost of Outfit.—In the following estimate the minimum cost has been fixed at the point below which it is not advisable to go. Materials and instruments can be bought cheaper, but they are as a rule unsatisfactory. It may be necessary, however, in some cases to buy a less costly outfit than is here given:

	Minimum.	*Maximum.*
Compasses, with attachments	$3.00	$7.50
Ruling-pen	1.40	1.90
T-square	25	1.50
Triangles	50	1.75
Curve	20	45
Scale	50	1.00
Protractor	25	50
Inks (black and red)	50	50
Paper (24 sheets 22″ × 15″)	1.00	1.00
Miscellaneous	40	50
Total	$8.00	$16.60

To the above list may be added materials for tinting, costing about 75 cents, and a drawing-board, in case one is not furnished by the school, costing from 50 cents to 75 cents.

CHAPTER II

THE USE OF THE DRAWING INSTRUMENTS *

14. The Pencil.—Pencil lines should be as fine and light as possible and still be clearly visible. Bearing on hard with the pencil will cut the paper and leave a mark which cannot be erased. The pencil should be sharpened to a *thin* wedge-shaped lead at one end (see Fig. 2), and a *sharp* round-pointed lead at the other end. The flat lead is used for drawing lines; the round lead for marking points, lettering the drawing, and all similar work. Lines are drawn with the flat side of the pencil lead pressed lightly against the ruling-edge, the pencil itself being held nearly vertical. Lines should be so close to the ruling-edge that they are scarcely visible until the edge is moved away. To insure this, it may be necessary to incline the pencil-top slightly outward, thus bringing the lead in contact with the *lower* corner of the ruling-edge. The hand holding the pencil should be in a position similar to that of Fig. 10, page 27, steadied by sliding on part of the little finger. The pencil should always be *drawn*, not *pushed*. Thus, in general, lines are ruled from left to right and from the bottom up.

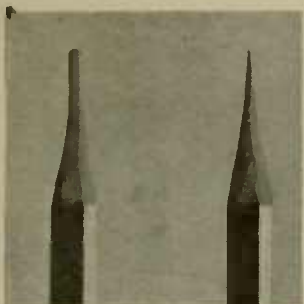


FIG. 2
Two views of the wedge-shaped lead

15. The T-Square.—The T-square is used with its head held firmly against the left-hand edge of the board. A line drawn with it in this position is called a horizontal line. Any number of horizontal lines may be drawn by sliding the T-square up or down. Horizontal lines are drawn from *left* to *right*, the pencil or pen being guided by the

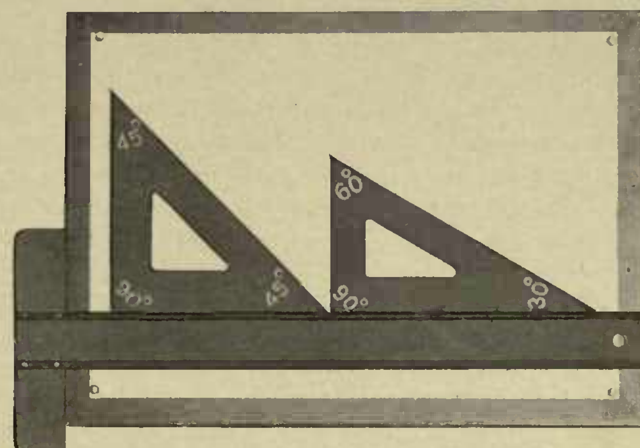


FIG. 3

* In this chapter the intention has been not to give a single unimportant direction, nor one not based upon the common experience of the best draftsmen. The beginner is urged to follow the directions as closely as possible, even though the reason for doing a thing in a certain way may not at first always be apparent. Habits formed at the start are not easily changed. Extra precautions are therefore necessary on the part of instructor and student that the latter may acquire early the shortest and best methods of work.

The student is not expected to read this chapter from beginning to end, but to study each article as it becomes necessary for progress in the work. The best results will be obtained by rereading the most important articles, such as that on the use of the ruling-pen, several times during the course.

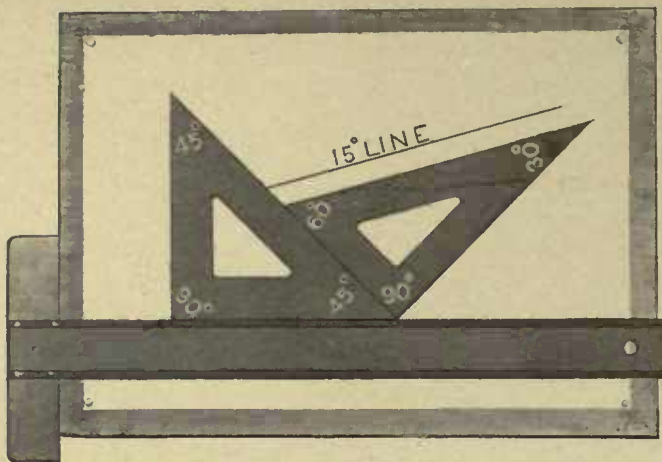


FIG. 4

upper edge of the T-square blade. Do not use the lower (or nearer) edge of the blade. The T-square is held in position with the left hand pressing its head against the board, leaving the right hand free to draw the line. The T-square is not to be used with its head against the top, bottom, or right-hand edges of the board. If, however, a draftsman draws with his left hand, he will need to use the T-square on the right-hand instead of the left-hand edge of the board. The habit should early be acquired of *feeling* the head in perfect contact with the edge of the board before starting to draw a line.

16. The Triangles.—(*a*) The two triangles commonly used are shown in Fig. 3. One triangle has two angles of 45° each and a right angle; the other has a 30° angle, a 60° angle, and a right angle. The first is called a 45° triangle, the second a 30° or 60° triangle. These triangles are used for ruling straight lines other than horizontal lines, for drawing parallel lines, for erecting a line perpendicular to any other line at any given point, and for drawing lines at certain angles to the horizontal. Various other uses to which the triangles may be put will occur to the draftsman after he becomes accustomed to working with them.

(*b*) *Vertical Lines.*—Vertical lines may be drawn with either triangle by placing a short side against the T-square. (See Fig. 3.)

(*c*) *Lines Making a Given Angle with the Horizontal.*—A 15°, 30°, 45° or n° line is understood to mean a line making an angle of 15°, 30°, 45° or n° respectively with a horizontal line. By placing one edge of the 30° angle of the triangle against the T-square a 30° line can be drawn in four directions from any given point. By using the other angles, 45° and 60° lines can likewise be drawn. By combining the two triangles (Fig. 4 and Fig. 5) 15° and 75° lines can be drawn. Thus by means of the T-square and triangles a circle can be divided

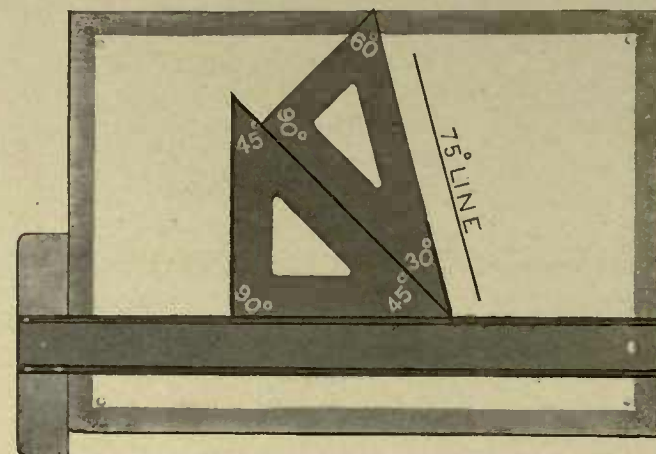


FIG. 5

into twenty-four equal segments by drawing from its centre 15°, 30°, 45°, 60°, and 75° lines in each of the quadrants formed by a horizontal and a vertical line intersecting at the centre of the circle.

(*d*) *To Draw One or More Lines Parallel to a Given Line.*—Make any edge of one of the triangles coincide with the given line and bring an edge of a second triangle into perfect contact with one of the two remaining edges of the first triangle (Fig. 6*). Hold the

* In Figs. 6, 7, 8, and 9 the original position of the first triangle is shown by the parallel line triangle drawn on the paper.

second triangle perfectly stationary and slide the first triangle upon it (Fig. 6). Either triangle may be used for the first one, a little practice enabling one to choose the most convenient arrangement for any given case.

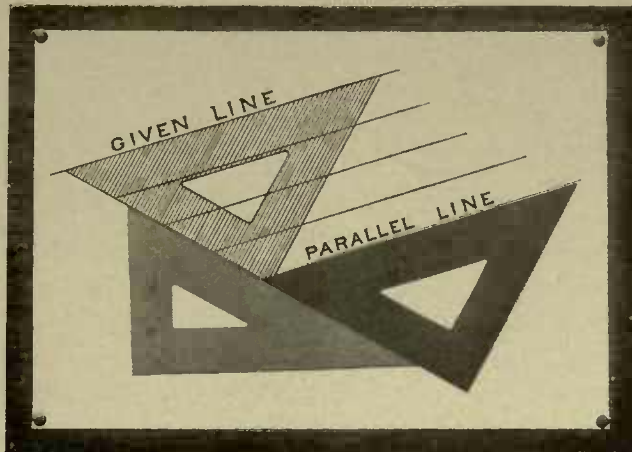


Fig. 6

(*e*) *To Erect a Perpendicular to any Line at any Given Point.*—Make one edge of the right angle of either triangle to coincide with the given line (Fig. 7). Bring an edge of a second triangle into perfect contact with the hypotenuse edge of the first triangle. Slide the first triangle upon the second, as indicated in Fig. 7.

(*f*) *Second Method.*—Make the hypotenuse edge of either triangle coincide with the given line (Fig. 8). Bring an edge (preferably the longest edge) of a second triangle into contact with one of the two remaining edges of the first triangle. Holding the second triangle stationary, turn the first triangle to the position shown in Fig. 8. This method can often be used where the first method cannot.

(*g*) In all of the three methods here given, the greatest care should be exercised to prevent the stationary edge from slipping; the second triangle being held firmly in place with the left hand until the first triangle has been moved to the desired position; the left hand can then hold both triangles, leaving the right hand free to use the pencil (Fig. 9). If only one line is to be drawn, it is evident that when the first triangle has been moved to its final position the second triangle need no longer be held in place. In large drawings it will often be found of advantage to use the T-square in place of the stationary triangle.

17. The Ruling-pen.—To ink in a drawing well requires great care and some experience. The beginner should not attempt to ink in his drawing until he can make a clear-cut straight line with reasonable certainty. To insure this, practice inking straight pencil lines. It is good practice, also, to ink in squares, rectangles, and triangles until not only the lines themselves are good, but the corners and intersections also. Corners should be very definite. Be careful to stop each line at exactly the right point, for ragged corners and poor intersections indicate careless drafting.

Before starting to ink, try the pen on a piece of paper *like that upon which it is to be used*, to determine the proper width of line. (It is well to keep part of a sheet especially for this purpose.) Adjust

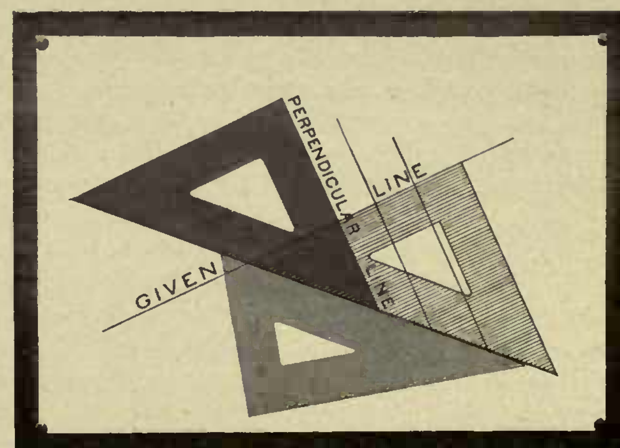


Fig. 7

the pen by means of the thumb-screw, opening or closing the nibs until a firm, clear line of medium width is obtained. If the line is ragged or the pen fails to work, it is probably because the nibs are not exactly of the same length, or because they are not sharp enough.

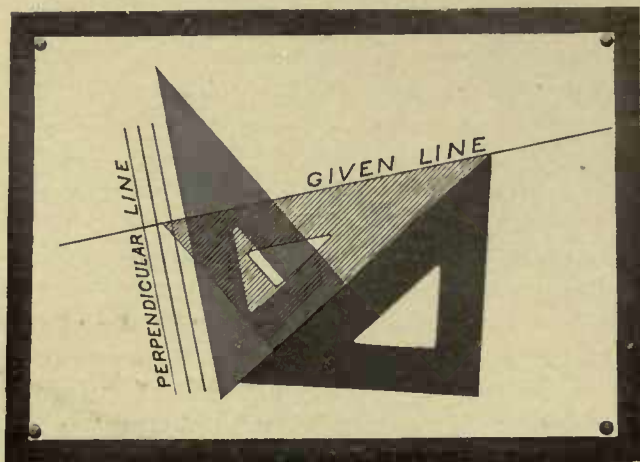


FIG. 8

A nib which is too short or too dull will leave *its* side of the line more or less broken. The ink oftentimes can be made to flow by moistening the end of a finger and touching it to the point of the pen. The best of pens become dull with use, and, as it becomes necessary, each draftsman should sharpen his own pen according to the directions of Art. 5.

To fill the pen, insert a common writing-pen full of ink *between* the nibs. Prepared inks usually have some device for filling the pen in the stopper of the bottle, designed also to be inserted *between* the nibs. Another way is to dip the ruling-pen itself into the ink, wiping the outside of the pen *clean* before using. In whatever way the pen is filled no ink should be allowed to remain on the *outside* of the nibs. Do not overload the pen, but, on the other hand, before commencing a line be sure there is ink enough to last its length, as it is difficult to "piece" or continue a line after refilling the pen. The flow of ink will be much more satisfactory if the charge is kept from becoming so small as to cause the ink to dry or thicken in the point of the pen. In fact, the only way to draw fine lines successfully is by frequently cleaning and refilling the pen.

The pen should be held almost perpendicularly, *thumb-screw out*, with both nibs pressing evenly on the paper (Fig. 10). The pen may be inclined *slightly* in the direction in which it is moved, but the natural and common error is to incline it too much. It is a mistake not to acquire early the correct method of holding the pen. The best pens incorrectly held produce poor lines. Do not press the side of the

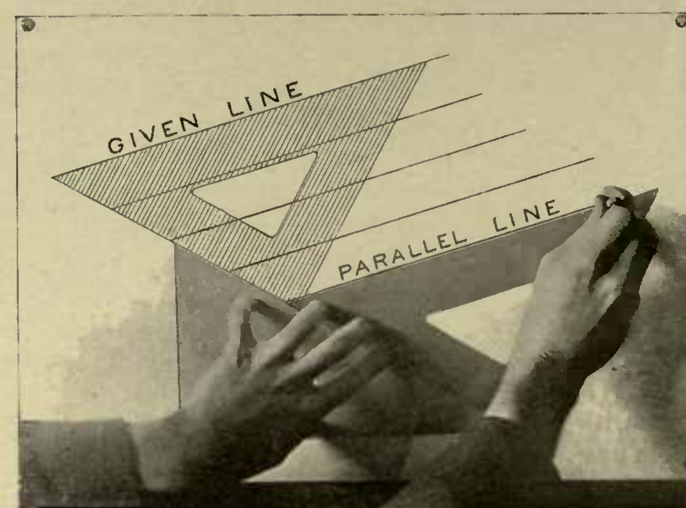


FIG 9

pen-point too heavily against the ruling-edge, as the nibs will be pushed together and the width of line will vary. A certain "touch," familiar to good draftsmen, brings the pen *lightly* but *firmly* in contact with paper and ruling-edge at the same time. *Steady the hand by sliding on the end of the little finger.* The pen should be moved

from left to right, and should be *drawn*, not *pushed*. See that there are no small particles of dust or lint in its path.

FIG. 10

Never push the pen backward over a line. If a line is not well drawn the first time it is rather difficult to "patch it up." The best method is to go over it a second time in the same direction, taking care not to widen the original line. Do not ink too close to the T-square or triangle, but place the ruling-edge so that it does not quite coincide with the pencil line. Endeavor to get into the easiest position to ink a line, even though it become necessary to walk around the drawing. (For this reason many draftsmen prefer to stand while inking.) Keep the ruling-edge *between* the line and the body, so that in moving the pen the tendency is to draw it *against* the ruling-edge, otherwise the pen is apt to be pulled *away* from it, making a break in the line. When the line is inked remove the T-square or triangle by drawing it *away* from the line or towards the body to avoid blotting or blurring.

When several lines meet in a point, if possible ink *from* and not *towards* the point, otherwise too much ink will gather at the intersection of the lines. Allow one line to dry before inking another. The same precautions are necessary in inking acute angles.

If the *top* or *left-hand* lines are inked first, and the draftsman works *down* or to the *right* respectively, time will be saved which would otherwise be lost in waiting for lines to dry. In inking in small details, place one triangle so that the lines to be inked lie within the open space in the centre of the triangle. A second triangle can then be laid across the first and used as a ruler in any direction without blurring wet lines.

When the pen is set at the proper width, avoid changing its nibs until all lines of that width are inked. The pen is easily cleaned by placing a piece of cloth between the blades and forcing it out through the end without loosening the thumb-screw. India-ink dries quickly, therefore do not lay the pen aside for any length of time without cleaning. Ink left to dry in the pen will almost surely corrode the points; for this reason the pen should be kept bright and clean when not in use.

18. The Compasses.—(*a*) Before using the compasses adjust them as follows: Insert the pen attachment in place of the one containing the pencil lead. Set the needle-point so that the pen-point and the shoulder on the needle-point are even when the compasses are closed. Replace the pen by the pencil lead (previously well sharpened), and adjust the latter so that it is even with the needle-point when the compasses are closed. The needle-point can now be used with either pen or pencil without being reset, the pencil alone needing readjustment from time to time as it wears off. Of the two ends of the needle, the one with a shoulder should be used, as it is designed to keep the point from making a large hole in the paper.

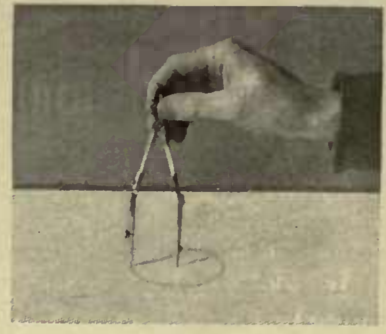


FIG. 11

(*b*) In using the compasses bend both legs so that each will be perpendicular to the paper when the arc or circle is drawn (see Fig. 11). Be particularly careful to do this when the pen attachment is used, for in no other way can the nibs of the pen be made to bear evenly on the paper.

(*c*) Most compasses are provided with a cylindrical handle at the head. In using the compasses, hold this handle rather loosely between the thumb and forefinger, and *let it roll between the two* during rotation. Allow the compasses to lean a little in the direction of revolution (which is clockwise), and bear down slightly on the pen or pencil, but not on the needle-point. In inking, however, the latter should be firmly fixed in its proper place before touching the pen to the paper,

otherwise it is apt to slip. On the other hand, the hole made by the needle-point should be as small as possible. When a point is used as a centre for several arcs or circles, extra care is necessary to prevent the hole from becoming too large, in which case it will be unsightly, and will prevent accurate work. In setting the needle-point on any particular centre, guide it to place with a finger of the left hand.

(*d*) The circumference of a circle should be inked with one continuous motion, an even pressure of the pen upon the paper being kept throughout. Stop the pen exactly at the end of one revolution, lest the line be made uneven by further inking.

(*e*) Circles and arcs of circles should be the first part of a drawing to be inked in, as straight lines are more easily drawn tangent to curves than the reverse.

(*f*) The lengthening bar is used for arcs or circles of greater radius than can be drawn with ordinary compasses. For very large arcs, "beam compasses," designed for the purpose, are used. For circles of one inch diameter or less, "bow compasses" are used, ordinary compasses being too clumsy for such small circles.

(*g*) Note that many of the directions for the use and care of the ruling-pen, such as filling, cleaning, sharpening, etc., apply also to the pen belonging to the compasses.

19. The Dividers.—Dividers are chiefly used for dividing a line into any number of equal parts, and for transferring distances from one part of the drawing to another. *They should not be used for transferring distances from scale to paper.* Compasses can be used as dividers, but the accuracy attained will not be as great.

Let it be required, for example, to divide a line into seven equal parts. Open the dividers until the space between the two points is equal, at a guess, to about one-seventh of the length of the line. Beginning at one end, step off seven spaces on the line. Suppose the last point falls short of the end of the line by about one-half an inch. Since the error has been multiplied seven times, make the space between the points of the dividers about one-fourteenth of an inch greater than before, and apply the dividers seven times again. Thus, by trial, the error is constantly reduced until the dividers are set correctly. (Three such trials at the most should be sufficient.) In using the dividers in this way, one or the other of the points is always on the line, the two points alternating front and rear. The point in front is used as a pivot, the *semi*-revolutions being alternately to the right and left of the line. In doing this, it is not necessary to make holes in the paper. Accuracy and neatness require that the points of the dividers should simply rest on the surface of the paper.

When a distance to be transferred from one part of the drawing to another cannot easily be laid off with the scale, the dividers are used. The thumb-screw is for opening or closing the dividers slowly, and its value is evident in setting the points to a known distance.

20. The Scale.—(*a*) Much time may be wasted by the faulty use of the scale. To lay off distances, place the scale on the paper and mark points with the round-pointed lead of the pencil, making sure they come exactly opposite the proper divisions on the scale. In measuring distances along a line, the edge of the scale should, of course, be *close* to the line throughout its length. Do not transfer distances from scale to paper by means of the compasses or dividers. Never use the scale as a ruler.

(*b*) It is evident that there are many objects, the drawings of which cannot be made full size and come within the limits of the paper; they are accordingly drawn to a *reduced* "scale." When, on the other hand, objects are very small, it is often convenient to make the drawing to an *enlarged* scale. The ordinary method of making such drawings is to assign to the inch an arbitrary value, so chosen as to make the drawing the desired size. Thus every inch on the scale may represent a foot on the object, in which case the scale is said to be "one inch to the foot." If one inch represents four inches, the scale is "three inches to the foot," or quarter size, and so on indefinitely. Sometimes the scale is very small, as in map-work, where one inch often represents several hundred feet. When one inch represents two inches the scale is simply "half size."

There are special scales made for this kind of work, the use of which is explained in Art. 21. If an ordinary scale is used it is better

(unless the drawing is made "half size") *not* to reduce the dimensions of the object by arithmetic, but *to read directly from the scale itself.* This becomes easy by *changing in the mind the value of each division on the scale.* Thus, if making the drawing "one inch to the foot," *think* of each inch as representing one foot. To lay off six feet three inches one would at once go to the six-inch mark and then to the quarter-inch mark beyond. Again: If the scale is three inches to the foot, or "one-fourth size," *think* of each inch as representing four inches and each quarter inch as one inch. To lay off six and one-half inches one would count off six quarter inches (or, better still, go at once to the one and one-half inch mark), and one-eighth of an inch beyond would be the required point. It is frequently necessary to estimate small distances. If, for example, in the first illustration it had been required to lay off six feet *two* inches, one would go *two-thirds* of the quarter inch beyond the six-inch mark. It is in such cases that the special scales are of distinct advantage. (See Art. 21.)

21. Architect's Scale.—The end space of the architect's scale is divided into twelve equal parts. For example, on the scale used for

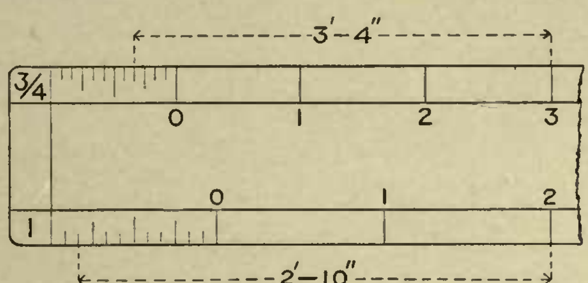


Fig. 12

1 in. = 1 ft., the end inch is divided into twelve parts, each one of which *represents* an inch. The other inches are not thus subdivided, but are numbered, the zero point being between the first and second inch. Thus the second inch from the end of the scale is marked 1, the third 2, and so on. To lay off $2'-10''$, for example, from a point, place the mark 2 at the given point; zero on the scale will then be two feet away, and (since the end space is divided into twelfths) ten spaces beyond zero will be opposite the point required. (See Fig. 12.)

The other scales referred to in Art. 8 are constructed and used in a similar manner. Inspection of Fig. 12 will make clear, for example, how $3'-4''$ would be laid off with a scale of $\frac{3}{4}$ in. = 1 ft.

End spaces are often divided into twenty-four or forty-eight equal parts, in order that half-inches and quarter-inches can be read off.

22. The Curve-ruler.—(*a*) To ink in a curve smoothly by means of a curve-ruler is one of the most difficult things a draftsman has to do, and nothing but persistent, careful practice will enable one to attain satisfactory results. A series of points through which the curve must pass is given. Sketch the outline in pencil, free-hand, through these points, and ink in small portions with the curve-ruler, drawing from left to right. The curve will coincide with the pencil outline *for a short length only*, and great care is necessary to make the different sections join well. To insure a smooth curve, it is well to let the edge of the ruler coincide with a small portion of the curve beyond the points where any particular section is begun or stopped. In inking, always keep the blades of the ruling-pen tangent to the curve by allowing the handle to turn between the thumb and fingers.

(*b*) In inking parabolas, hyperbolas, and similar curves with a sharp turn, the common difficulty is in avoiding a slight angular break in the curve at the turn. The part of the ruler used for one side of the bend should be such that if the line were continued it would nearly coincide with the curve for a short distance the other side of the bend. When the ruler is reversed for the curve on the other half of the turn, the angular break referred to should not result. A *small* portion of a narrow turn can usually be better drawn with the bow compasses than with the curve-ruler.

CHAPTER III

WORKING KNOWLEDGE *

23. To Fasten the Paper to the Board.—(*a*) Fasten the paper (one sheet only) to the board by means of thumb-tacks, one in each corner, pressed down until the heads are flush with the paper. Insert a tack in one corner, make the paper square with the board by means of the T-square, stretch it diagonally across to the other corner, and insert a second tack; stretch the paper diagonally in the other direction and insert tacks. It is not so essential to have the paper square with the board as to have it stretched flat and smooth. In large sheets it may be necessary to put additional tacks along the edges. A tack can be temporarily removed when it interferes with the work.

(*b*) In certain kinds of work the best results can only be obtained by stretching the paper while damp. This is done by moistening the whole sheet, with the exception of a border of half an inch on the outside, until it is limp. Secure this dry border to the board with mucilage, which must set before the body of the paper dries, so that the latter may be stretched uniformly by its own contraction. Use a sponge in smoothing the paper and work from the centre out. In gluing the edges commence with the centres of opposite edges, leaving the corners until last. Cut the paper from the board when the drawing is finished, following the edges around successively in order.

(*c*) Dealers in paper endeavor to keep it flat; the draftsman should keep it flat also. If kept in rolls it will not lie smoothly on the board unless it is first wet and stretched according to the above method.

24. Precautions to Insure Neatness.—The paper and instruments must be clean to start with, and kept so, if possible. The triangles and T-square are liable to become dusty. It is well to wipe them with a damp—not a wet—cloth before commencing work, and as often afterwards as necessary. The paper should be kept clean by means of a stiff brush or a silk or linen handkerchief. There is little danger of applying the brush or handkerchief too frequently. After the eraser has been used, always brush the surface of the paper *clean* before proceeding with the work.

In inking, watch the paper in front of the pen, and if a particle of dust or lint gets in the path, blow it away before it can get into the pen and spoil the line. Beware of wet lines or a pen too full of ink, or dropping the pen on the paper—most common causes of blots.

25. Arrangement.—(*a*) The pleasing appearance of a sheet of drawings depends largely upon the arrangement of the different parts or figures. The appearance as a whole should be symmetrical; this is secured by the judicious spacing of the figures with respect to each other as well as to the edges of the paper. It is often difficult to estimate the space which any one figure will occupy when drawn, or what the general effect will be when compared with the other adjacent figures. No general rule can be given, but the attention of the draftsman is called to this point as one of importance.

* Skill in handling the instruments must be supplemented by a general knowledge of the *methods of work*. The nucleus of this "working knowledge" can be early acquired from a few important directions based on common experience. There are many habits of accuracy and little devices for time-saving which are second nature to a good draftsman, and which go so far towards making one an expert. Once started right, the draftsman's own experience is his best teacher.

The foot-note at the beginning of Chapter II. applies to this chapter also.

Arts. 23 to 33 are to be read before the first plate is drawn. Arts. 34 to 45 are put in this chapter for convenience of reference later in the course.

(*b*) A border line more or less elaborate can be used with good effect where the drawing itself is more or less elaborate. A single heavy line, or a heavy line with a light line just inside of it, will usually make the most suitable border. One needs to be quite sure that his drawing *is* elaborate before adding a fancy border. When there are several sheets of drawings of the same object, it is customary to make the different sheets and borders of one size. In simple, plain drawing, it is, perhaps, in better taste not to put any border on at all.

(*c*) It is well to note here that while the figures of the plates of this course are perhaps too simple to require border lines, nevertheless for convenience in locating the problems such lines are drawn. In each plate, unless otherwise noted, the space within the border lines is divided into as many equal rectangles as there are problems, and each figure is located symmetrically with respect to the sides of its own rectangle. It is evident that such a method of arrangement would avail little had not each figure been previously designed to fit into its assigned place. In some cases it has been thought desirable to locate the figure exactly, the distances of some starting-point from two sides of the rectangle being given at the end of the printed problem. (See page 2.)

26. Rapid Drafting.—(*a*) A rapid draftsman is not only quick with his instruments, but he also uses the best methods and does things in the most economical order. He builds up a figure intelligently, looking ahead as far as possible. The skeleton outline, or "limiting lines," are drawn first, the details last. *Like operations are grouped.* All lines which can be drawn with one position of the T-square or triangles are finished before commencing another set of lines. When the scale is in hand, all necessary measurements which can be made at that time are laid off.

(*b*) All arcs or circles which can be described with a single setting of the compasses are drawn before changing that setting. Unnecessary pencil lines are left out—the fewer construction lines, as a rule, the better. One can save time by knowing what to slight and what not to slight. The same care is not necessary for all classes of work nor for all operations on the same drawing. This is especially true of the preliminary work in pencil, as is more fully stated in Art. 27. Many similar hints for rapid drafting could be given, but the above should suffice to start the beginner on the right track.

(*c*) It may be hardly necessary to add that steady rather than hasty work is to be desired. Undue haste on the part of the beginner usually means failure more or less complete. The most skilful draftsmen are obliged to be careful *how* they hurry.

27. Pencilling.—(*a*) Drawings are usually made in pencil and then inked in. In working drawings, instead of inking the pencil lines a tracing of them is usually made. (See Arts. 43 and 148.) Pencil clearly but lightly. A HHHHH pencil may be used if the drawing is to be traced without previous inking, otherwise use a HHHHHHH pencil.

(*b*) *Care should be taken to draw accurately in pencil.* The pencil lines should be true guides for the inking-pen. It is the common experience that the accuracy of a drawing is seldom improved upon in the inking in. Thus, for example, when parallel lines should be $\frac{1}{4}''$ apart, as in Prob. 1, Plate I., if they are not exactly $\frac{1}{4}''$ apart in pencil they are not apt to become so when inked in. On the other hand, it is not necessary to stop each pencil line at exactly the right place. The same care is necessary in making the ink lines stop where they should, whether the pencil lines do or not. It saves time, therefore, and in some cases makes the intersections and corners more definite to let the pencil lines overrun *slightly*, the projecting ends being erased *after the whole drawing has been inked in.* Likewise in drawing a pencil line along which a given distance is to be laid off, make it a little longer than necessary and then mark off the required distance, leaving the ends to be erased later.

It is often unnecessary to draw a line from end to end, especially if it is a construction line. For example, in drawing two diagonals to find the centre of a rectangle, draw an inch or less of one line near the centre, and simply cross it with the other. Many similar cases occur in all construction work, where time would be wasted and unnecessary erasing caused by drawing entire lines.

28. Inking.—(*a*) As a rule, do not commence to ink a drawing until it is finished in pencil. The width of line to be used varies with the size of the drawing—the larger and more open the drawing the coarser the lines may be. Lines should not, however, be so coarse as to make the drawing seem crude, nor so fine as to make it indistinct.

Lines of medium width are best suited for open plain figures, like those in the plates of this course. It is always well to test a pen after setting its nibs to see if the line is right, but this should not be done on the sheet itself nor on the drawing-board. A separate piece of paper should be kept at hand for this purpose.

(*b*) It is sometimes necessary to ink in a line of unusual width, as, for example, a heavy border. The safest way of doing this is to draw several parallel lines of medium width, about their own thickness apart, and fill in between with another set of parallel lines when the first are dry. Another and more common method of inking such a line is to draw the two outside edges and fill in between with a brush or with heavy lines from the inking-pen. In very wide lines this too often results in leaving a large quantity of ink, which warps the paper and takes a long time to dry.

29. Erasing.—(*a*) It is well to avoid erasing pencil lines until the drawing is nearly finished. Many draftsmen prefer to leave the erasing until after the drawing is inked. If the eraser must be used, as, for example, to *correct* the pencil drawing, the surface of the paper should be brushed *clean* again before anything else is done. If the eraser does not of itself wear off fast enough to keep clean, rub it occasionally upon the drawing-board, allowing some particular spot on the wood to be worn clean and remain so for this purpose. In erasing after the drawing has been inked, avoid rubbing *across* ink lines, but erase in *between*, otherwise the lines are apt to become dimmed or blurred if not thoroughly dry. Much erasing with the pencil-rubber will deaden any ink line, destroying the sharp, black effect.

(*b*) To make corrections on inked drawings, use a hard rubber ink-eraser. Do not press too heavily on the paper, as no time is saved in this way, and it injures the surface for further inking. For the same reason lines should seldom be scratched out with a knife. An exception occurs when a "dashed" line has been inked in full by mistake. A full line is easily made "dashed" by taking out *short* portions of it at regular intervals with a crosswise motion of the knife-point and smoothing over the breaks with a pencil-eraser. The *surface* of large blots may be removed with a knife before the eraser is applied. If the surface of the paper is injured in erasing, rub briskly with a clean hard substance (ivory is good) until the paper becomes "polished" and ready for the ink.

(*c*) When it is desired to erase a portion of a drawing and leave adjacent portions untouched, cover the part not to be erased with a triangle. The erasing can then be carried clear to the latter's edge, but no further. Thus, by shifting the triangle, as much or as little of the drawing as desired can be erased. A flat piece of celluloid, with a straight narrow slit in it, is useful in erasing portions of lines, the rubber being applied through the slit. A sponge rubber or crumbs of wheat-bread can be used to clean the drawing when finished.

30. Laying off Measurements.—(*a*) In laying off several successive distances on a line, set the scale once for all and then do not move it. For example, suppose it is required to lay off five successive spaces, $\frac{1}{4}''$, $\frac{1}{2}''$, $\frac{3}{4}''$, $1''$, and $1\frac{1}{4}''$ long respectively. Place the edge of the scale along the line with its zero point at the starting-point. The spaces would then be marked off opposite the $\frac{1}{4}''$, $\frac{3}{4}''$, $1\frac{1}{2}''$, $2\frac{1}{2}''$, and $3\frac{3}{4}''$ divisions of the scale. In this way the last division ($3\frac{3}{4}''$) equals the sum of all the spaces. A wrong method is that in which the zero point of the scale is moved up each time to the end of a space to lay off the next space. Thus an error in a single space affects all succeeding spaces as well, and an opportunity for errors to accumulate is thereby afforded. This is not true of the first method.

(*b*) In very accurate work, a needle set in a wooden handle is useful for marking distances. *Very small* prick-marks are made, which are easily kept track of if small, free-hand pencil circles are drawn around them.

(*c*) Many times measurements, having once been laid off, can be projected on to other lines by means of the T-square or triangles. It may be also noted that the eye can become so trained that small distances can be estimated with surprising accuracy. Thus, in certain classes of work, much tedious use of the scale is avoided.

(*d*) In order that the diameter of a circle may be exactly right, mark off its radius on a straight line each side of a point, and open the compasses until the circumference of the circle passes through the

extreme points. This is better than to take the radius directly from the scale, although the latter method is sufficiently accurate for ordinary work.

(*e*) Do not lay off distances with the compasses or dividers when the scale can be used.

(*f*) Time and annoyance will be saved in the end if the draftsman will form the habit of frequently checking his measurements. Simple inspection with the eye alone will usually detect large errors, and it is wise to look occasionally at the drawing *as a whole.* For small errors, apply the scale a second time wherever there is the least doubt of accuracy. Many other ways of applying checks will occur to one as the work progresses.

31. Use of the Triangles.—The beginner is warned against trusting to the extreme corners of the triangles, as they soon become rounded. A common error is the attempt to use one triangle alone. For example, if a 30°, 45°, 60°, or perpendicular line is to be drawn to a horizontal line, it is wrong to make one edge of the triangle coincide with the given line and then draw the required line by means of another edge. In this case the T-square should be in a horizontal position a little below the given line, and the triangle is held against it. Thus a triangle is almost always used against the T-square or another triangle, except in inking.

32. Line Notation.—Custom differs in respect to line notation. In addition to the ordinary full lines, the following ink lines will be used in this course:

(*a*) *Invisible lines* of an object, such as rear edges, are represented by dashes from $\frac{1}{16}''$ to $\frac{1}{8}''$ long; the spaces between should be as *short as possible* and still have the dashes distinct from each other. The thickness of line is the same as for ordinary full lines.

(*b*) *Construction lines* and *projecting lines* are lighter and more delicate than "invisible lines," consisting of little dashes as *short* and *fine* as can well be made. The object sought is to make the drawing itself stand out boldly, while the construction lines seem in the background.

(*c*) *The axis of a figure* should be inked in with a short and a long dash alternating; the long dash should be a little more than $\frac{1}{8}''$ long, the short dash a little less than $\frac{1}{16}''$ long.

(*d*) *The trace of a plane* is represented by a dash and a dot alternating; the dash should be about $\frac{1}{8}''$ long. When the trace is invisible there are two dots between the dashes.

Care should be taken in drawing the above lines to secure an even appearance by making the spaces *very short* and the dashes of uniform length. Nothing tends to give a more finished appearance to a drawing than well-drawn "invisible" and "construction" lines. When too hastily drawn they can seriously mar an otherwise excellent drawing.

33. Lettering the Drawing.—Letters and printed words on a drawing should in general be either horizontal or vertical, being read from left to right and from the bottom up respectively. They should be printed in the open spaces in such a way as not to obscure the drawing.

Free-hand lettering is done with an ordinary writing-pen. For heavy letters a ball-pointed pen is used. Every draftsman should learn to letter well. The appearance of a good drawing can be spoiled by poor lettering. Good lettering consists of plain, even, clear-cut letters, well proportioned, well spaced, and quickly made.

The beginner will do well to draw pencil guide-lines for letters and words. If the letters are made small and *close together*, it will be easier to space them properly. Most letters are not printed with a continuous stroke, as in writing. In forming each letter much depends on the number of strokes, the order or sequence of strokes, and the direction in which the pen is moved, instructions for which are admirably given in "Lettering for Draftsmen, Engineers, and Students: a Practical System of Free-hand Lettering for Working Drawings," by Charles W. Reinhardt. If the student will get this book and carefully follow its directions, he can hardly help acquiring, with a reasonable amount of practice, a neat, legible style of free-hand lettering.

The greatest precision in lettering (especially if the letters are large) is only attained by the use of the drawing instruments, and

when the results warrant the extra time expended, draftsmen resort to this method. Letters made in this way should be well proportioned and well spaced. A text-book on "Plain Lettering," by Prof. H. S. Jacoby, is a very complete treatise on the accurate proportioning and spacing of letters. The Roman, Gothic, and other standard letters required by draftsmen are treated in detail, and numerous examples of titles and printed notes given.

34. The Use of Colored Inks.—The use of colored inks is only desirable when it makes the drawing more easily understood. Aside from black, red is the color most commonly used. Construction lines and "dimension lines" (see Art. 149) are sometimes inked in red. Non-essential or subsidiary parts of a drawing, introduced for the purpose of making the main drawing clearer, can be kept in the background by using red ink, especially when a tracing (see Arts. 43 and 148) is made. Thus, when two parts of an object fit together, and one part has already been made or provided for; in a drawing of the second part, the first, which ordinarily would not appear at all, is sometimes drawn in red ink to better show the connection. In maps and profiles, proposed lay-outs and grades are usually drawn in red to distinguish the new from the old.

35. To Mix India-ink.—For fine work it is safer for the draftsman to prepare his own ink from Chinese stick-ink. This is done as follows: Place as much water in the saucer as will suffice for the amount of ink required. Rub the end of the stick on the bottom of the saucer with a rotary motion until the mixture is of the desired density. The liquid will appear black before it really is; to get it just right, test it in the inking-pen. It should flow readily, dry quickly, and the resulting line should be jet black, and not easily erased or blurred when dry. If the line fades as it dries, add more ink to the mixture from the stick. If it lacks the other desired properties, try another make of ink. Chinese inks vary in quality, but it does not follow that the most expensive kinds are the best. Try different sticks until one is found which is satisfactory. Wipe this dry after using to prevent it from crumbling, and it will last for a long time. The following precautions should be observed: Clean the saucer before using. Avoid dust or undissolved particles of ink in the mixture—they clog the pen. Keep the mixture covered when not in use. Do not use ink more than two or three days old, but mix a fresh supply. Do not try to use ink which has dried in the saucer.

Colored inks may be prepared from artists' water-color cakes in a similar manner.

36. Shade Lines.—(*a*) Edges of an object which lie between light and dark surfaces are often represented by lines about twice as wide as other lines. Such lines are called shade lines. They are frequently omitted, especially in working drawings. They add, however, to the appearance of a drawing, and when properly constructed are of value in understanding or reading it. Directions for their use (which differs in different kinds of drawing) will be found in Arts. 53, 128.

(*b*) In shading a circle only part of the circumference is made heavy, the line gradually decreasing each way until it merges into the original width. To produce this effect, first draw the circle with the ordinary width ink line. Imagine a line drawn through the centre of the circle to that point of the circumference where the greatest width of line is desired. Shift the needle-point a *very little* from the centre along this line either towards or away from the point on the circumference, according as it is desired to have the extra thickness fall outside or inside the original line. An arc can now be drawn which will start from the original circumference, deviate farthest from it at the desired point, and come back to it again in such a way that it cannot be seen where it begins or stops. It requires some care to prevent the needle-point from slipping back into the original centre. The setting of the compasses should not be changed from that used in drawing the original circle.

(*c*) A second method (which is not recommended to beginners unless used with great care) is to keep the same centre and *spring* the compasses by pressure of the hand, making the point of the pen gradually deviate from the circle and return again, thus giving the increased thickness of line on part of the circle. This is a quick method and satisfactory in the hands of an experienced person.

37. Line Shading.—Parts of a drawing representing curved

surfaces are sometimes shaded by means of parallel lines of different widths and distances apart, so drawn as to produce a variation of shade corresponding as nearly as possible to that on material objects. This effect is obtained by gradually increasing the width of lines, at the same time diminishing the distance apart, or vice versa. This kind of shading does not have the soft and finished appearance obtained by some of the other methods, but it is useful in many cases. In practising by oneself much help may be derived from the many excellent advertising cuts which appear in the engineering papers and periodicals.

Line shading can be executed with comparative ease on cylindrical surfaces, but is very difficult on cones and spheres. It will be found a thorough test of the ruling-pen, because it requires all widths of lines down to the very finest, and any ragged or irregular edges will be brought into surprising prominence. For examples of line shading, see Plate III., page 105.

38. Parallel-line Shadows.—Shadows on different parts of an object are sometimes represented by parallel lines similar to section lines—the darker the shadow, the closer together the lines. By a judicious use of such lines, especially in isometric, cabinet, and perspective drawings, the object may be made to "stand out," and the effect will be more satisfactory than that produced by a simple outline drawing.

39. Section Lines.—When an object is cut in two by an imaginary plane (see Art. 90), that part of the drawing representing the portion of the object cut is cross-lined with parallel lines called *section lines*. These lines are usually 45° lines in one direction or the other, drawn about $\frac{1}{16}''$ to $\frac{1}{8}''$ apart. The larger the section the farther apart the lines, and the farther apart the lines the easier it is to secure a uniform appearance. The distances apart are made equal by the eye alone, not by actual measurement. The tendency on the part of a beginner is to make the lines too near together and the spaces unequal. The lines are not to be first drawn in pencil; even if the drawing is to be traced, better results will be secured by drawing the section lines once only, and then in ink. When two different pieces meet, the section lines in one should slope in the opposite direction from those in the other. Section lines should be much finer than the ordinary lines, hence ink slightly thinned best serves the purpose. It is better to leave small open spaces for letters and figures than to render them obscure by drawing section lines over them.

Many "section liners" designed for drawing parallel lines are to be had. Some of these are very useful, but a draftsman should be able to section-line nicely without them. Drawing section lines for any length of time is trying to the eyes. In such a case, or where considerable accuracy is required, it is better to use a section-liner. The "Sphinx," an inexpensive section-liner made by Weber & Co., Philadelphia, is recommended.

As in the case of line shading, excellent examples of section lining are to be found in cuts of machinery in engineering papers.

40. Tinting.—(*a*) Tints are chiefly used in map-work, where flat tints of different colors are laid on to distinguish the different portions of the map. Colors are also employed in working drawings to represent different materials. When it is desired to represent a shadow cast by an object, or to shade the drawing of the object itself, gray tints made of India-ink are used.

(*b*) For colored tints, cakes of water-colors prepared for the use of artists are best. To mix either the colored or the gray tints, proceed in exactly the way described in Art. 35, but make the mixture much less dense, rubbing the stick on the end of the finger frequently dipped in water, instead of on the bottom of the saucer. Tints for shadows should be light gray, not black. When a very dark tint is required, it is better to put on several successive layers of a lighter shade, waiting each time for the preceding one to dry, than to attempt a single dark tint at first.

(*c*) The surface to be tinted must be clean. All pencil lines within the boundary should be avoided; if drawn and not erased, they can be seen through the tint; if they are erased, the surface of the paper is injured and a smooth, even wash cannot be laid on. It is well to tint before inking. If the drawing is inked first, water-proof ink must be used. In shadow-drawing, *do not ink in the outline of the shadow.*

(*d*) The rear of the board should be elevated a little so that the surface may be sloping. If the top of the drawing-table cannot be inclined, block up the board. The brush used is described in Art. 2. Take the tint from the *surface* with the side of the brush to avoid specks of ink in the bottom of the saucer. Small particles of ink transferred to the paper will dissolve and leave small blots. Apply the brush moderately full of the tint to the upper left-hand corner of the outline and draw towards the right. This will leave a small "pool" of tint, which must be worked down the paper, moving the brush across from side to side. This pool should almost, but not quite, run down the paper of itself. It must be kept full by additions from time to time with the brush. The tint *must not be painted on.* The secret of success is to *coax* the tint down the paper, keeping it moving all the time, and not allowing it to stand in one place longer than in another. In laying on the same wash, do not go over a place twice to "touch it up"; it will usually make it worse. The whole operation must be done rapidly; it is better to let the brush overrun *a little* OUTSIDE the outline than to spend too much time on the edges, allowing the interior of the tinted space to dry and become streaked. The tint outside the boundary line can be removed *when thoroughly dry* by covering the portion not to be erased with a triangle (or curved ruler, if the outline is curved), and using a pencil-eraser.

(*e*) When the "pool" reaches the bottom of the outline, squeeze the brush comparatively dry—it will then take up the surplus tint like a sponge. The whole surface should now have a uniform flat tint. Better results are usually obtained if the surface is previously gone over with clean water, precisely as in tinting. When the surface, held towards the light, ceases to glisten, the tint can be laid on a little more leisurely and carefully, because it is not so quickly absorbed by the paper, and therefore dries more slowly. If the paper is too wet, the tint will run.

41. Graduated Tints.—Curved surfaces are not shaded uniformly, as described in the last article, but successive layers of tint are applied, each covering a wider area than the preceding. Thus, to shade a cylinder, lay a narrow strip of tint along the element of darkest shade. When dry, apply a second strip a little wider than the first, and so on. If these successive layers overlap each other uniformly, a

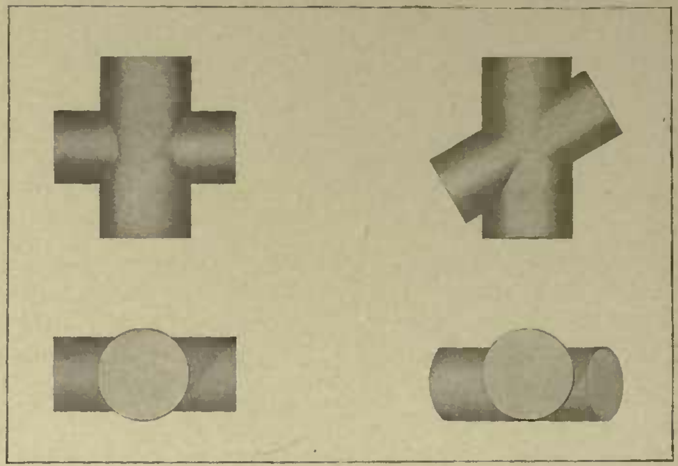


FIG. 13

fairly good effect is produced. But this method will always show streaks where the different coatings overlap. To make a perfectly continuous gradation, it is necessary to soften or draw out the edge of each strip while it is still wet, using clean water in the brush. A double-ended brush will be found convenient for this process, one end for tint and the other for water. This work must be done quickly, for the edges cannot be softened after they have begun to dry.

Brush-shading requires great care and dexterity, and considerable practice is necessary to do it well.

42. Blue-print Process.—It is evident that in many cases more than one copy of a drawing is required, especially if it is a working drawing. The blue-print copying process, used almost exclusively, may be briefly described as follows: The original drawing is traced on transparent cloth or paper prepared for that purpose. Paper sensitive to light is also required. This paper is prepared by covering one side of a clean white sheet of ordinary tough, smooth paper with

a chemical wash, and drying it in a dark room. If the prepared paper is washed before being exposed to the light, the water will remove the chemicals, and the paper will be as white as it originally was; but if exposed and then washed it will become a permanent blue. If the tracing is laid over the paper when exposed, the light cannot penetrate the ink, and that part of the paper directly beneath the lines will remain unturned. If the prepared paper is then washed, a white drawing on a blue background will result. It is evident that any desired number of prints can be made from the same tracing.

The prints are usually taken in a printing-frame, which has some device for holding the tracing and the sensitive paper flat and smooth against a glass front. The side of the tracing-cloth or tracing-paper upon which the drawing has been made is placed next to the glass, and the chemically prepared side of the process paper is next to the tracing.

43. Tracings.—Tracing-cloth of different widths can be had by the yard or roll. One side of the cloth is smooth and glazed, the other rough and dull. The drawing can be made on either side. Ink lines can be best erased from the glazed side—a point in its favor. Blue-prints will also be slightly clearer if the smooth side is used. Sometimes the drawing is made directly on the tracing-cloth, and then the dull side is preferable, because pencil lines are more easily drawn on it.

After completing a drawing in pencil in the usual way, pin the tracing-linen over it—the lines underneath will be plainly visible if they are moderately heavy—and ink on the transparent cloth. The latter should be stretched flat and smooth. Before beginning to ink, sprinkle the surface with powdered chalk and rub gently with a soft cloth. This is necessary to make the tracing-cloth take the ink, especially when working on the glazed side. Specially prepared chalk in a box with perforated cover is the most convenient form for use. A *sharp* inking-pen is required for tracing—it is more important than ever that the pen should be just right.

Tracing-cloth is very susceptible to moisture, and if left on the board several days is liable to become ruffled and uneven by its expansion. All important lines should therefore be traced the same day, if possible. As a further precaution, tear off a strip about half an inch wide from each of the two edges of the cloth before pinning it down.

Ink dries more slowly on tracing-cloth than on ordinary paper, and care must be taken to avoid blotting the moist lines. If the cloth is of poor quality, the ink is liable to strike through and spread; such cloth is useless for tracing. Red ink does not print well, but is used to some extent for dimension lines or other portions of a drawing which it is desirable to render less prominent.

Lines, letters, and figures should be made heavier on tracing-cloth than on an ordinary drawing, in order that the blue-print may be clear. It is not unusual to find a beginner carefully putting on almost microscopic figures with a crow-quill pen. Such fine work practically disappears on the blue-print. Figures, above everything else, should be bold and clear, since they cannot be guessed at.

Erasing should be done very carefully with a *sharp* knife and hard rubber; too much erasing wears a hole through the cloth. After erasing, the smooth surface must be restored before inking by rubbing with soapstone. Powdered pumice applied with the tip of the finger will remove ink from tracing-cloth without destroying the surface. If a bad mistake is made, it is sometimes possible to cut out a portion of the cloth and insert a new piece in its place, gluing the corners or edges. This can be done very neatly.

Tracing-paper is often used, and is very satisfactory, though less durable than cloth. Water-proof ink is best for drawing on either.

44. Blue Process Paper.—Prepared paper for blue-prints can be purchased in rolls of different widths at such a low price and of such excellent quality that it hardly pays to prepare it for oneself, unless a large quantity of it is required. If it is desirable, however, to make it, the chemicals may be used in the following proportions:

1 oz. red prussiate of potash in 5 oz. water.
1 oz. citrate of iron and ammonia in 5 oz. water.

At time of use, mix and apply with soft sponge or broad, thin brush to one side of hard white paper. Keep the prepared paper in a dry, dark place until wanted for use; it must be fresh to get the best results; with old paper the lines will be gray instead of white. The proportions of the chemicals in the blue-print mixture may be varied considerably without any effect, except to change the time required to print.

In a bright, hot sun, from three to six minutes' exposure, according to the quality of the paper, should give a good copy. After printing, wash thoroughly in a sink of running water, letting each sheet remain in the bath a short time, if convenient. When it is required to make corrections or additions to a blue-print, a special preparation must be used to make white lines, and a solution of quick-lime and water, well shaken up, will be found satisfactory. To obliterate white lines or figures, go over them with a blue pencil.

45. Miscellaneous Geometrical Constructions.—(*a*) *To Plot a Given Angle:* Let it be required to draw a line $\overline{ac}$, making an angle of $x°$ with $\overline{ab}$ (Fig. 14). On $\overline{ab}$ lay off any distance, as $\overline{ad}$. At d erect a perpendicular, $\overline{de}$, equal in length to $\overline{ad} \times \tan. x$. Through e draw the line $\overline{ac}$.

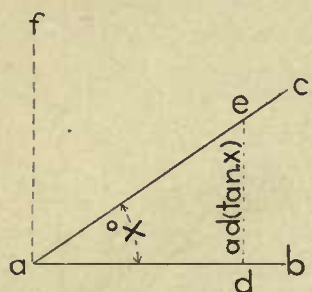


FIG. 14

If the angle x is greater than 45°, plot $x-90°$ with the line $\overline{af}$, using the same method. If the angle x is so large that the line $\overline{ac}$ is in one of the other three quadrants, plot the angle which $\overline{ac}$ makes with the nearest line (horizontal or vertical, as the case may be) through a.

(*b*) *To Draw a False Ellipse:* When the difference between the major and minor axes of an ellipse is small, a close approximation to a true ellipse can be drawn with the compasses, describing four arcs, as follows:

(Fig. 15.) The distance from the centre of the ellipse to c is equal to the difference between the major and minor axes—i.e., $aa-bb$. The distance from the centre of the ellipse to c' is equal to three-fourths of $aa-bb$. c, c, c', and c' will be the centres of the four arcs, each arc ending in the points n, as indicated in the figure.

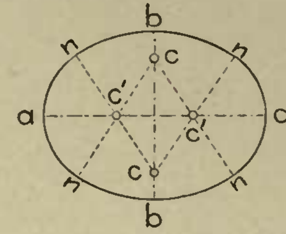


FIG. 15

In ellipses too narrow for this method, find points on the ellipse by the method given in the next article; draw end arcs and middle arcs as far as they can be drawn without deviating from the ellipse. (The centres of these arcs will be on the axes, and are found by trial.) Complete the ellipse by joining the arcs with the curve-ruler.

(*c*) *To Find Points on a True Ellipse: Trammel Method.*—On a straight-edge (a calling-card will answer the purpose) mark off ed and ec, equal respectively to the semi-minor and semi-major axes of the ellipse. Move the straight-edge, keeping d on the major and e on the minor axis. The point c will move in an ellipse. A series of points can thus be obtained, through which the ellipse can be drawn with the curve-ruler or by any other method.

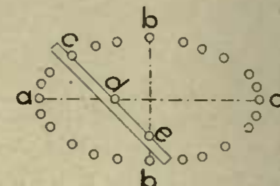


FIG. 16

(*d*) *To Construct a Parabola:* Let it be required to draw a parabola through the three points, a, b, and c (Fig. 17). Draw cd and bd. Divide bd into any number of equal parts, 1, 2, 3, etc. Divide cd into the same number of equal parts, 1′, 2′, 3′, etc. Draw lines from c to 1, 2, and 3. Intersect the line to 1 by a perpendicular from 1′, the line to 2 by a perpendicular from 2′, and so on. Through the points thus obtained, draw half the parabola with the curve-ruler. Complete the other half by the same method.

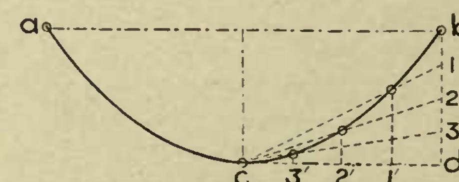


FIG. 17

(*e*) *To Construct a Hyperbola: First Method.*—In the left-hand branch (Fig. 18) let the curve pass through any point, as *e*, and be symmetrical with respect to the two lines $\overline{ab}$ and $\overline{bc}$. Draw any line through *e*, as $\overline{gh}$, *g* and *h* being on the lines $\overline{cb}$ and $\overline{ab}$ respectively. Lay off $hx = ge$ and *x* will be on the hyperbola. By drawing several lines through *e*, and laying off on each the distance from *e* to the nearest end of the line backwards from the other end, a series of points will be obtained through which the curve may be drawn with the curve-ruler.

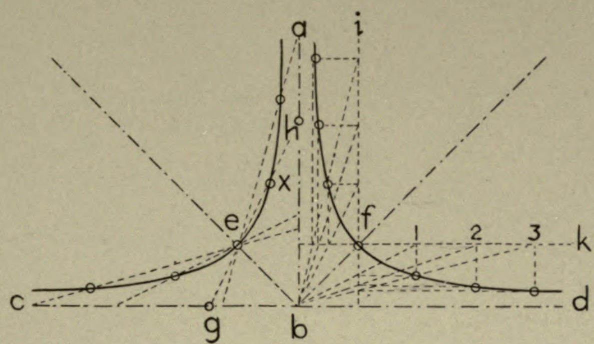


FIG. 18

Second Method.—In the right-hand branch (Fig. 18) *f* corresponds to *e* of the left-hand branch. Through *f* draw the horizontal line $\overline{fk}$ and the vertical line $\overline{fi}$. On $\overline{fk}$ mark off points 1, 2, 3, any convenient distance apart. Draw lines from *b* to 1, 2, and 3, and where these lines cross the vertical line through *f* draw horizontal lines. From 1 drop a perpendicular to the upper horizontal line, from 2 to the next lower line, and so on. Through the points thus obtained draw half the curve, and complete the other half by a similar method, as indicated in the figure.

CHAPTER IV

ISOMETRIC PROJECTION AND CABINET PROJECTION

46. A drawing in isometric projection or in cabinet projection represents an object *approximately* as it appears to the eye. These two projections are used as substitutes for true perspective to save time and labor. A drawing in perspective represents an object as it *actually* appears to the eye; but in mechanical drawing this is not, as a rule, essential. An approximate outline in cabinet or isometric is more easily and quickly drawn, and will usually answer every purpose.

ISOMETRIC PROJECTION

47. FUNDAMENTAL PRINCIPLES.—Isometric drawing is based on the following fundamental principles, as easily applied as they are remembered:

(*a*) *There are three lines called isometric axes* (see Fig. 19). *They are a 30° line in one direction, a 30° line in the other direction, and a vertical line.* Thus these three lines, drawn from the same point, form a flat Y.

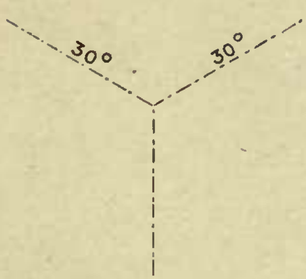


FIG. 19.—ISOMETRIC AXES

(*b*) *The isometric axes represent lines mutually perpendicular to each other, and correspond to the three dimensions, length, breadth, and height.* A MEASUREMENT ON THE DRAWING CAN ONLY BE LAID OFF PARALLEL TO ONE OF THESE AXES.

Measurements along a horizontal line, for example, are not made in isometric drawing.

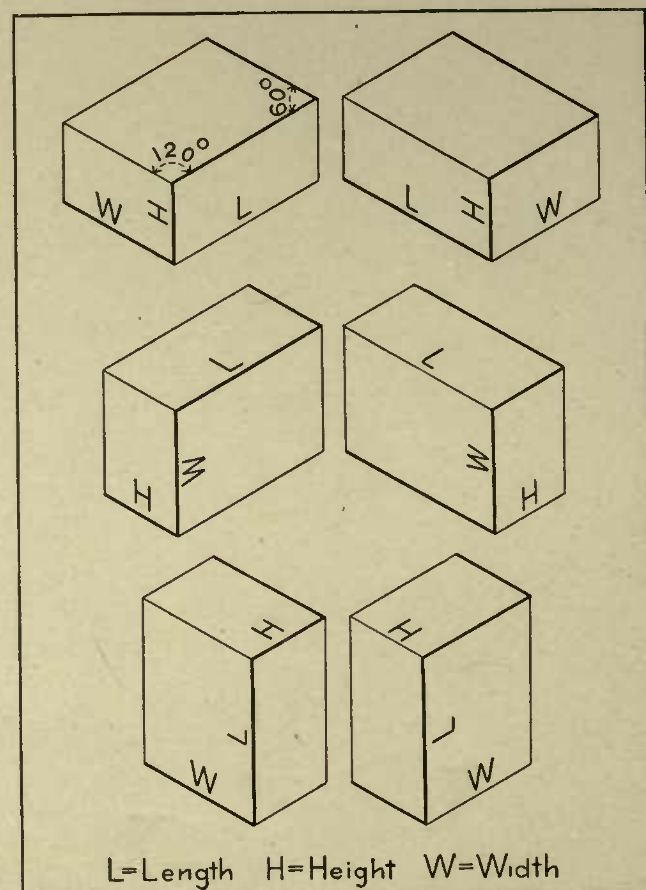


FIG. 20

Illustration: In Fig. 20 there are six different views of the same block. In the two upper figures the height (H) is measured on a vertical line, the width (W) and the length (L) on 30° lines.

(c) In Fig. 20 the three figures on the right are similar to the three on the left. Taking the figures in pairs, the only difference between two which correspond is that in one case the *longest* 30° lines extend to the *left*, while in the other they extend to the *right*. Either method is correct. When the length and width of an object are different, two such views can be drawn for each of its three positions, the draftsman choosing the one best suited to his purpose.

(*d*) *Vertical lines in the object are vertical lines in the drawing. Lines parallel in the object are parallel in the drawing. Right angles in the object are usually either 60° or 120° in the drawing* (see Fig. 20).

48. Non-rectangular Objects.—In drawing *rectangular* objects, the application of the foregoing principles is easy. *Non-rectangular* objects are also easily drawn in isometric; but it takes more time, and the results as a rule are less satisfactory. The method is evident from the following examples:

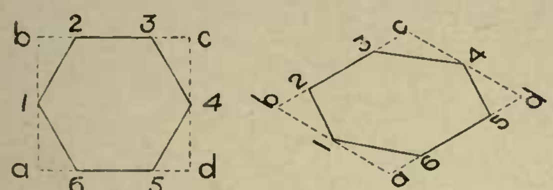


Fig. 21

(*a*) *First Method.*—Illustration: Let it be required to draw an isometric hexagon. First draw a true hexagon of the required size (Fig. 21). Draw a rectangle such that each of the six apices of the hexagon will be in a side of the rectangle. Draw this construction rectangle in isometric, and measure along its sides to locate the apices of the *isometric* hexagon, as indicated in the figure on the right (Fig. 21).

(*b*) Any non-rectangular plane figure which can be inscribed in a rectangle can be drawn in isometric in a similar manner. Any non-rectangular solid which can be inscribed in a rectangular block can be drawn in isometric by a method similar to that indicated in Fig. 22.

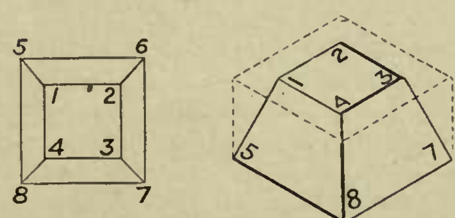


Fig. 22

(*c*) *Second Method.*—Let it be required to draw any irregular plane figure, as, for example, the one shown in Fig. 23. As this figure cannot be inscribed in a rectangle, draw any two co-ordinate axes, *ab* and *ac*. These axes can then be drawn in isometric, and each limiting point of the figure located by its co-ordinate distances, as indicated by the construction lines (Fig. 23).

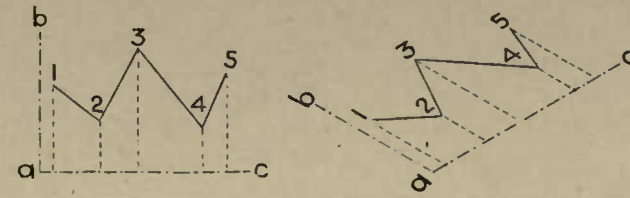


Fig. 23

Irregular solids can be drawn in a similar manner by using a third axis and a third ordinate. The three co-ordinate axes will correspond to the isometric axes.

(*d*) The hexagon (Fig. 21) and the irregular figure (Fig. 23) have each been drawn in a *horizontal* plane. To draw them in a vertical plane, the rectangle in the first case and the co-ordinate axes in the second case should be drawn in the plane of a *vertical* and a *horizontal* isometric axis, instead of in the plane of two horizontal isometric axes.

49. Isometric Scale.—An isometric projection of an object, if drawn to full scale, makes the object seem larger than it really is. To offset this, an "isometric scale" is sometimes used. Such a scale can be constructed as follows: Lay off true inches on a 45° line and drop vertical lines; these intercept isometric inches on a 30° line. The inch may be subdivided in a similar way into as many parts as are necessary (Fig. 24). If the isometric scale be transferred to the edge of a strip of card-board it can be used like an ordinary scale.

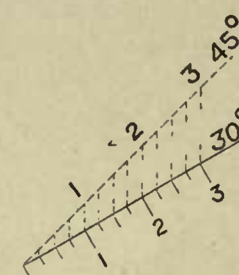


Fig. 24

50. Circles in Isometric Projection.—To construct a circle in the upper face of the cube (drawn to isometric scale) of Fig. 25. Draw the diagonals and the isometric lines *m*, *m*. The semi-major axis *ac* (equal to the true diameter of the inscribed circle) can be measured equally on each side of *c*, *with the regular scale of inches.* Or it can be found graphically by dropping a perpendicular from *c* upon a 45° line through *d*; *bc*=*ac* is the semi-major axis. The ends of the minor axis *n*, *n* are found by drawing through *a* lines parallel to the

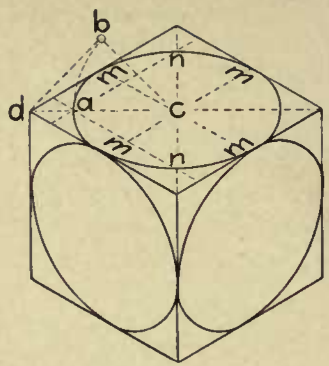


FIG. 25

sides of the cube. The axes and four tangent points being known, the ellipse can be drawn by circular arcs and curve-ruler, or by any other method.

If the cube is drawn to regular scale, the major axis of the ellipse will be longer than the actual diameter of the inscribed circle. The other directions will remain true. The major axis can always be found by the construction of Fig. 25 given above.

51. Isometric Circle.—A simpler way of drawing an isometric circle than that given in the preceding article is to find circular arcs to the ellipse without getting the axes at all. In Fig. 26 the ellipse is drawn from the four centres c, c', k, k'. To get centre k, lay off $bk=bm$. To get centre c, lay off $cm=ab=$ to a side of the circumscribed square. This method applies to the use of any scale and is a close approximation. The ellipse is not exactly tangent to the sides at m, but the error is not perceptible.

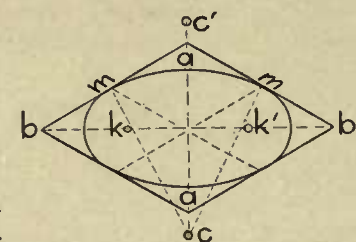


FIG. 26

52. Irregular Curve.—The method of drawing an irregular curve is illustrated in Fig. 27. The left-hand figure is the true shape of the upper and lower faces of a block. The right-hand figure is the isometric drawing of the same block, and the corresponding ordinates are marked with the same numbers, *1, 2, 3, 4, 5*. This method can be applied to a curve in space by using another ordinate.

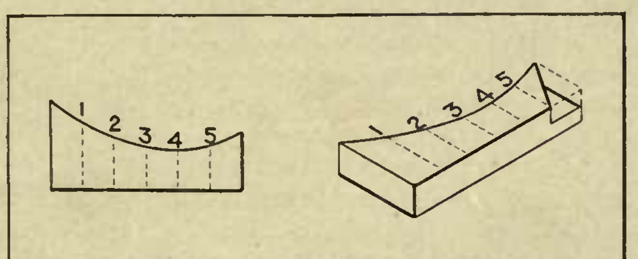


FIG. 27

53. Shadows in Isometric.—The method of drawing shadows in isometric is illustrated in Fig. 28. The rays of light are 45° lines. The shadow in this case is on a horizontal plane through the base of the cross. To find shadow of the point a, draw a 45° degree line through the point and drop a perpendicular to a'. The intersection of the 45° line through a, and a horizontal line through a', gives the required shadow as. Shadows of other points are found in a similar way. The work can often be shortened by remembering that horizontal *isometric* lines have for their shadows lines parallel to themselves. Thus $\overline{as\,cs}$ is parallel to the corresponding isometric line $\overline{ac}$. Shade lines representing edges, which cast shadows (see Art. 36), can usually be determined by inspection.

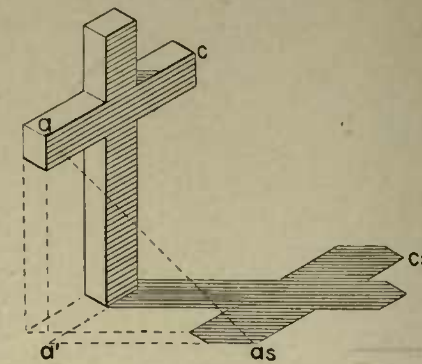


FIG. 28

For other examples of shade lines, see Fig. 20.

CABINET PROJECTION

54. (*a*) Cabinet projection is somewhat like isometric projection. The cabinet axes, however, are: A horizontal line, a vertical line, and a 45° line (see Fig. 29). All measurements on the drawing must be laid off parallel to these axes. *Measurements parallel to the 45° axis are half as long as the corresponding lines in the object.* Vertical or horizontal measurements are laid off to full scale.

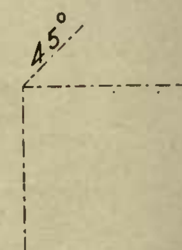


FIG. 29

Illustration: In Fig. 30 there are six cabinet drawings of the same block in different positions. The dimensions of the block correspond to those of the block of Fig. 20. An opportunity is thus given to compare isometric and cabinet projections. In the figures here given the 45° edges are marked their *true* length (L, H, or W, as the case may be), and not *half* this length ($\frac{L}{2}$, $\frac{H}{2}$ or $\frac{W}{2}$). They are drawn half length, however, according to the principle given in Art. 54 (*a*).

(*b*). It will be seen from the figures that in cabinet as in isometric projection the draftsman has a choice between a left and a right hand view for any given position of a block.

Can any additional views of the block (Fig. 30) be drawn?

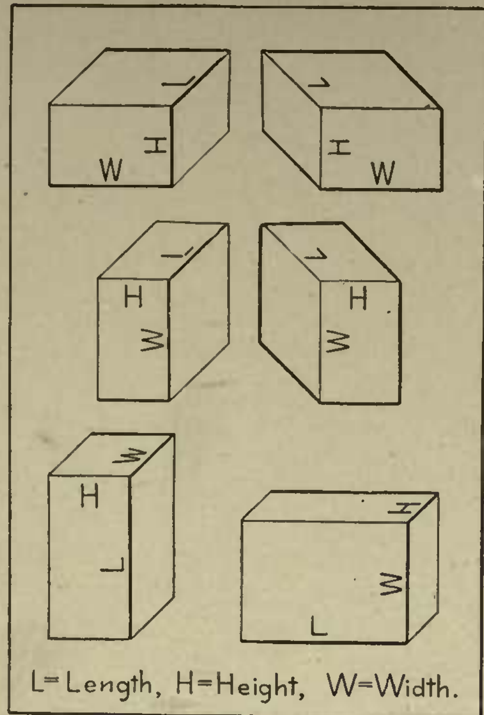


FIG. 30

55. Rules for Cabinet Projection.—The following rules can be given for drawing in cabinet projection:

(*a*) *Place one face of the object in, or parallel to, the plane of the paper; this will be full size, exactly like the face itself.*

(*b*) *All lines perpendicular to the front face will be 45° lines, half the length of corresponding lines of the object.*

(*c*) *To draw a* NON-RECTANGULAR *plane figure, or an irregular solid, in cabinet projection, use the methods* of Arts. 48 and 52, *drawing the construction rectangle, block, or co-ordinate axes, as the case may be, in cabinet projection instead of isometric projection.*

56. CIRCLES IN CABINET PROJECTION.—(*a*) Fig. 31 is the cabinet projection of a cube with inscribed circles. The front face is full size, and the four edges perpendicular to it are 45° lines and half length. To construct a circle in the top face, draw the diagonals of the circumscribed parallelogram, and mark the four tangent points *k*, *k*, *h*, *h*. To get points where the ellipse crosses the diagonals, draw perpendicular lines at *m*, *m*, in the front face, to the upper edge, and then 45° lines meeting the diagonals at *m'*, *m'*, *m'*, *m'*. Thus, eight points on the ellipse are known, four tangent points and four points on the diagonals. The ellipse should be sketched in pencil, and inked with the aid of a curve-ruler. This will require practice, but the draftsman should be able to construct a satisfactory ellipse in this way, without finding its axes.

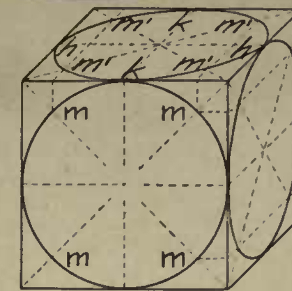


FIG. 31

(*b*) A short way of finding the points where the ellipse crosses the diagonals is to make the distance from the centre of the ellipse to *m'* on the longer diagonal equal to one-half of *hh*, and draw a 45° line through each of the points thus found. This is an approximate method, but accurate enough for practical purposes. It is not of much use to find axes, although it can be done without difficulty. The problem is recommended to the student as an exercise.

(*c*) If additional points on the ellipse are required (which rarely occurs), the following method will give two such points in each quadrant: From *a*, one corner of the square, Fig. 32, draw lines to the middle of the opposite sides, *m* and *n*. Let *b* and *b'* be the middle points respectively of *a n'* and *a m'*. The intersection of *b' n'* and *a n* is a point on the circle; the intersection of *b m'* and *a m* is another point on the circle. This is equally true of the ellipse which represents a circle. By repeating this construction in each quadrant, eight points of the ellipse can be obtained in addition to those found by the methods of the preceding articles.

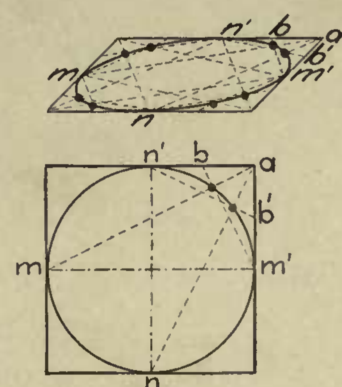


FIG. 32

This method is geometrically correct, and applies to any form of oblique projection, to isometric and to perspective.

57. Oblique Projection. — Cabinet projection is one of several systems of *oblique* projection. Another sometimes used differs only in the length of the 45° lines, which are made full length instead of half length. This system is a trifle easier to execute than cabinet, but the appearance is usually less satisfactory.

58. (*a*) Isometric Projection and Cabinet Projection Compared.

Isometric.	Cabinet.
Three axes parallel to which measurements corresponding to the three dimensions of space can be made.	Same.
One axis vertical; other two, 30° lines to right and left.	One axis vertical, one horizontal, one a 45° line.
Measurements may be made to true or isometric scale, but whichever scale is used it is the same for all isometric lines.	Measurements are full size on horizontal and vertical lines; half size on 45° lines.
No face of an object is drawn in its true shape and size.	The front face and others parallel to it are drawn true shape and size.

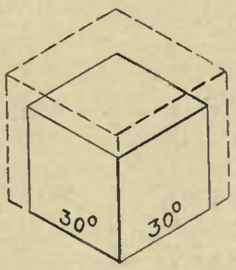


Fig. 33—Isometric Cube

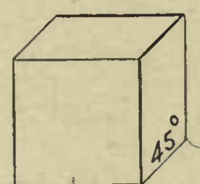


Fig. 34—Cabinet Cube

In Fig. 33 the cube in full lines is drawn to isometric scale. The same cube drawn to full scale is represented by broken lines. It is seen that the cube drawn to isometric scale corresponds to the cabinet drawing of the same cube (Fig. 34), while that drawn true size appears much larger.

As a rule, cabinet projection looks somewhat better, and is easier to execute than isometric projection. Each is especially adapted to the drawing of rectangular objects. Drawings of non-rectangular objects made in either of these two projections are usually unsatisfactory. Drawings to reduced or enlarged scale can be made in either projection.

(*b*) Advantages and Disadvantages of Cabinet and Isometric Projections.—The advantages and disadvantages of cabinet and isometric projections as compared with true perspective are:

Advantages.—(1) Time and labor saved. (2) Measurements can usually be scaled from the drawing itself.

Disadvantages.—(1) A picture drawn in isometric or cabinet is never a true picture. Lines which in perspective converge are parallel in isometric or cabinet; hence the drawing appears distorted and offends the eye. (2) One cannot choose the point of view from which to represent an object, as in perspective—often a serious drawback.

CHAPTER V

ORTHOGRAPHIC PROJECTION

59. Projection.—If from a point in space a straight line is drawn to a plane, the point in which the line meets the plane is a *projection* of the point in space. The line itself is a *projecting* line. The plane is a *plane of projection.*

60. Orthographic Projection.—*In Orthographic Projection:* (*a*) A plane of projection is either a *vertical* or a *horizontal plane.* The planes of projection are assumed as transparent.

(*b*) Every projecting line is *perpendicular* to the corresponding plane of projection. Hence projecting lines are either *horizontal* or *vertical* lines.

(*c*) The projection of a point on the vertical plane of projection is called its *vertical projection;* its *horizontal projection* is on the horizontal plane of projection. Hence *horizontal* projecting lines are used to find *vertical* projections, and *vertical* projecting lines to find *horizontal* projections.

Illustration: In Fig. 36, page 48, 1 represents a point in space. 1v represents its *vertical* and 1H its *horizontal projection.* The dotted lines represent *projecting lines.*

(*d*) A projection of a *line* may be found from the corresponding projections of its limiting *points.*

A projection of a *surface* may be found from the corresponding projections of its limiting *lines.*

A projection of a *solid* may be found from the corresponding projections of its limiting *surfaces.*

(*e*) In mechanical drawing, orthographic projection is used for the delineation of both the horizontal and the vertical projections of material objects upon two imaginary co-ordinate planes.

61. Angles of Projection.—(*a*) The two co-ordinate planes of projection (considered as infinite in extent) intersect at right angles, and thus form four *right diedral angles.* Denoting the horizontal plane of projection by H and the vertical plane by V, a point, line, surface, or solid is said to lie in the:

First Angle when it is above H and in front of V.
Second Angle when it is above H and behind V.
Third Angle when it is below H and behind V.
Fourth Angle when it is below H and in front of V.

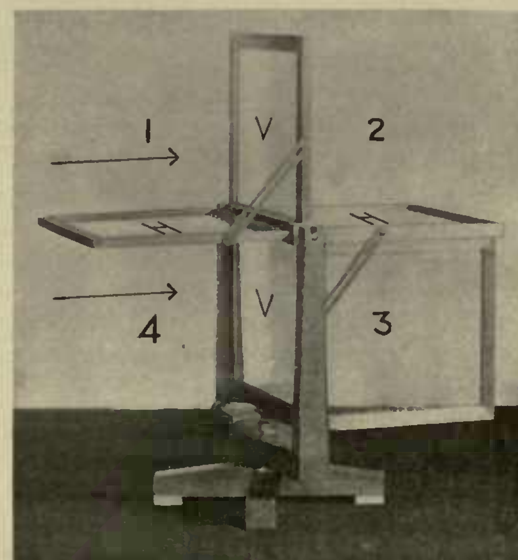


Fig. 35

In descriptive geometry (a higher and more extended study of orthographic projection) all four angles are used. In mechanical drawing, however, the object is usually assumed as lying wholly within one angle, no attention being paid to the other three.

(*b*) The *first angle* is the one still used by many draftsmen for working drawings, but the *third* affords a more convenient arrangement of views (projections), and is more in accord with modern practice. The fundamental principles of drawing are practically the same, no matter in which angle the object may be located, and a draftsman should be able to draw in any one of the four. Unless otherwise specified, the third angle will be used in all the problems of this course.

(*c*) NOTE: The model shown in the photograph on the preceding page represents *limited* portions of the horizontal and vertical planes. The angles of projection formed by these planes are therefore limited. It should always be borne in mind, however, that the planes and angles of projection are in reality infinite in extent.

The portion of the horizontal plane *behind* the intersection of the two planes and the portion of the vertical plane *below* this intersection are the planes of projection for an object in the third angle. Thus in this course little use is made of those portions of the planes containing the upper V and the left-hand H.

(*d*) A portion of a third plane (called the end or side plane of projection) perpendicular to the other two planes is shown in the photograph. If the portions of H and V not used for an object in the third angle be removed, the remaining portions of H and V, together with the end plane, correspond to the three transparent sides of the box of Fig. 36, page 48. The use of these planes of projections (including the end plane) will be explained in subsequent articles.

62. VIEWS.—(*a*) The projections of an object on H and V are called respectively its *Horizontal Projection* and *Vertical Projection*, or *Plan* and *Elevation*, or *Top View* and *Front View*. Of these three pairs of terms, *Top View* and *Front View* are to be preferred. They not only are definite, but they are also consistent with Bottom View, End View, Side View, or Rear View, terms commonly used in working drawings when the corresponding views of the object are shown.

(*b*) The projecting lines which determine any one view of an object are all *parallel* (since they are perpendicular to the same plane). These lines correspond to lines of sight; but lines of sight never are parallel (since the eye never is an infinite distance away); hence a projection *is never a true picture*. The term *view* must therefore be used only in the sense of a *projection*.

(*c*) REMARK: Unlike isometric and cabinet drawing, orthographic projection is not intended as a substitute for perspective. As a shadow may or may not resemble the object which casts it, so a projection may or may not look like the object projected. Thus, at the outset, this form of drawing is unnatural, and the imagination must be trained to overcome the tendency of the eye to look for a *picture* instead of a *projection*.

63. GROUND LINE.—The line in which H and V intersect is called the *ground line*.

64. THE DRAWING.—(*a*) *To Represent the Planes of Projection:* A horizontal line is drawn to represent the ground line. That portion of the paper above (or behind) this line represents one plane of projection; that portion of the paper below (or in front of) this line represents the other plane of projection.

The ground line may be drawn anywhere, its location depending upon the desired arrangement of the different views.

H is *in front of* and V is *above* the ground line when the *first angle* is the one used.

H is *behind* and V is *below* the ground line when the *third angle* is the one used.

(*b*) *The Relative Positions of Different Views:* The positions of the different views (or projections) with respect to the ground line and to each other are the same as would result if one of the planes of projection were revolved about the ground line until H and V are both in the same plane.

ILLUSTRATION: In Fig. 36, let the top of the box (which represents H) be revolved about the ground line until it is in the same plane with the front of the box (which represents V). The relative positions of the views (Fig. 37) will now correspond to those in the drawing (Fig. 38). I_H (which is in H) is *behind* (above) and I_V (which is in V) is *below* the ground line in both figures.

(*c*) In orthographic projection, any point in the *third* angle has its top view (horizontal projection) *behind* and its front view (vertical projection) *below* the ground line.

In using the third angle, it is well to accustom oneself to think of a *top view* as *behind* the ground line rather than *above* it. (Why?) On the other hand, it is obviously correct to speak of a *front view* as below the ground line.

(*d*) Orthographic projection thus requires of the imagination two distinct processes: (1) To conceive each view on the corresponding plane of projection. (2) To determine the positions of the different views with respect to the ground line and to each other when the planes of projection have been brought into one plane.

Eventually, as one becomes accustomed to this form of projection, he is less conscious of any action of the imagination. As a matter of fact, an experienced draftsman rarely thinks of the planes of projection at all, the different views of an object appearing to him as so many true pictures of it (although they are not).

65. (*a*) To be able to draw in orthographic projection, one needs a working knowledge of a few of the fundamental principles of descriptive geometry. In the following articles these principles are given in the form of propositions for convenience of reference. By means of the photographs, however, they become self-evident.

Remark: The working knowledge above referred to is indispensable. The sooner one acquires it, the sooner the work of drafting becomes more truly mechanical. This does not mean that the propositions should be learned by heart, but that a thorough understanding of them helps the imagination, and guides the reason in working out any new problem which the draftsman may encounter.

(*b*) In the photographs scattered throughout the remainder of the chapter, the glass sides of the box represent the planes of projection. (See Art. 61 *d*.) These photographs are intended to make clear how the views of a point, line, surface, or solid on the planes of projection are obtained. In many cases a second photograph shows the top glass (horizontal plane) revolved about the intersection of the top and front glasses (ground line) until the top and front glasses are in the same plane. This brings the views into the same relative positions that they occupy in the corresponding line drawing. Were it not for the perspective of the photograph, the views would be identical in outline with those of the line drawing. It should be noted that a view on the top glass when it is horizontal is greatly distorted by the perspective. Thus, in Figure 50, page 56, the view on the top glass is a true square, although it may not appear as such. In Figure 51 it is more nearly a square, because the upper glass was almost parallel to the plate in the camera when the photograph was taken.

When the end plane is used, it is revolved about the intersection of the front and end planes (vertical ground line) until the end and front planes are in the same plane. This brings the end view opposite the front view. (See Figures, pages 58 and 59.)

Remark: The danger in the use of such photographs is in becoming too dependent upon them. It is evident that it is not necessary to imagine an object enclosed in a glass box in order to make an orthographic drawing of it, and the beginner is cautioned against allowing this to become a permanent habit. When the fundamental principles are thoroughly understood, the glass box should be discarded. (See Note Art. 64 *d*).

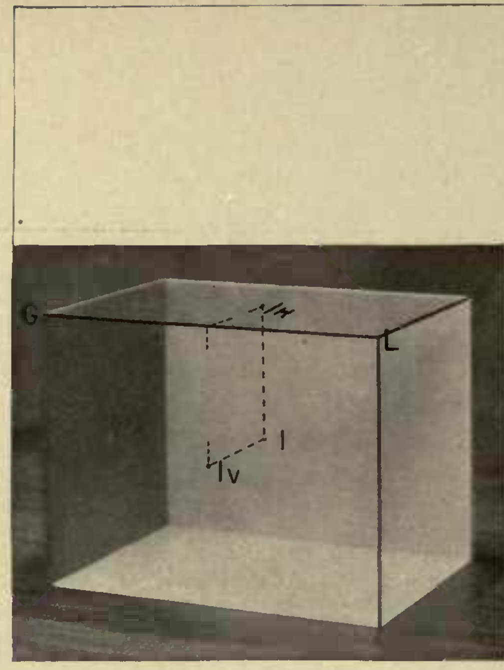


Fig. 36

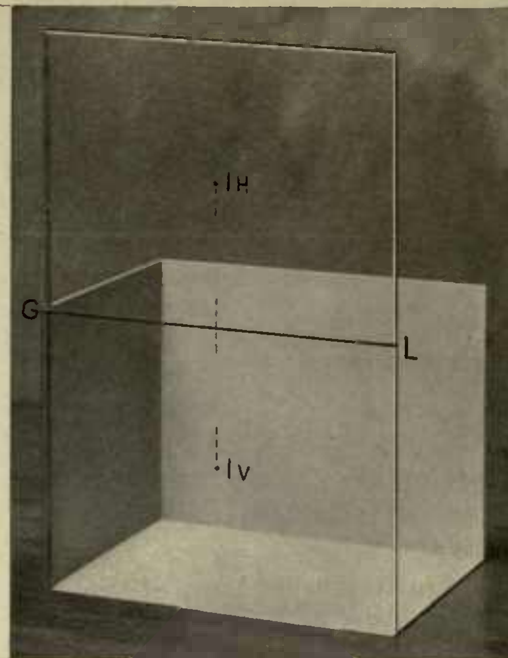


Fig. 37

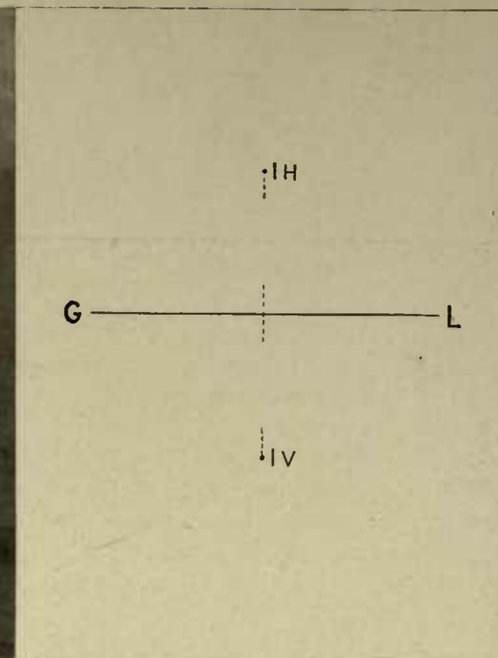


Fig. 38

66. A Point in Space (Figs. 36, 37, 38).

If 1H and 1V represent the top and front views respectively of the point 1 in space, it follows:

That the position of 1 is completely determined by these two views; hence:

(*a*) *Every point has two views (one on H, the other on V) by which its position in space is determined.*

That a plane can be passed through 1, 1H, and 1V perpendicular to the ground line; hence:

(*b*) *A point and its two views lie in the same plane perpendicular to both H and V—i.e., a plane passed through the two projecting lines.*

That the distance from 1H to the ground line is equal to the distance from 1 to V. The distance of 1V from the ground line equals the distance of 1 from H; hence:

(*c*) *The* TOP VIEW *of a point is as far* BEHIND *the ground line as the point itself is behind V. The* FRONT VIEW *of a point is as far* BELOW *the ground line as the point itself is below H.*

If a point is equally distant from H and V, its two views will be equally distant from the ground line.

That if the point 1 were no distance below H, 1 and 1H would coincide, and 1V would be in the ground line. If 1 were no distance behind V, 1 and 1V would coincide and 1H would be in the ground line; hence:

(*d*) *When a point lies in either H or V, one of its views coincides with the point itself, the other view will lie in the ground line.*

A point lying in both H and V would coincide with both of its views in the ground line.

THE DRAWING OF A POINT IN SPACE.

(See Art. 64.)

67. From Figures 37 and 38 it is evident that:

(*a*) *A point in space can be represented by its two views, neither of which is the point itself.*

A point, line, surface, or solid never has less than two views in true orthographic projection.

(*b*) *The two views of a point always lie in the same straight line at right angles to the ground line.*

This principle is continually used in finding one view of a point from the other view.

(*c*) ILLUSTRATION: Assume the point 1 (Fig. 36) to be 3″ below H and $3\frac{1}{4}$″ behind V. Applying the principles of Articles 66 and 67 to the drawing (Fig. 38), 1_H is $3\frac{1}{4}$″ behind the ground line. 1_V is 3″ below the ground line. The line joining 1_H and 1_V is perpendicular to the ground line.

If 1 were no distance below H instead of 3″, where would 1_V be?
Where must 1 be if both 1_H and 1_V are in the ground line?

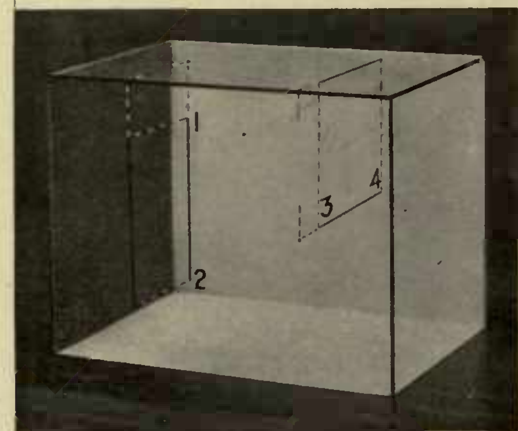


FIG. 39

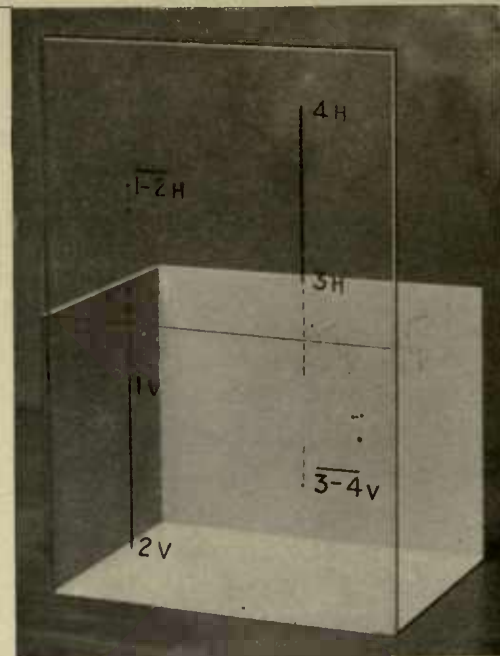


FIG. 40

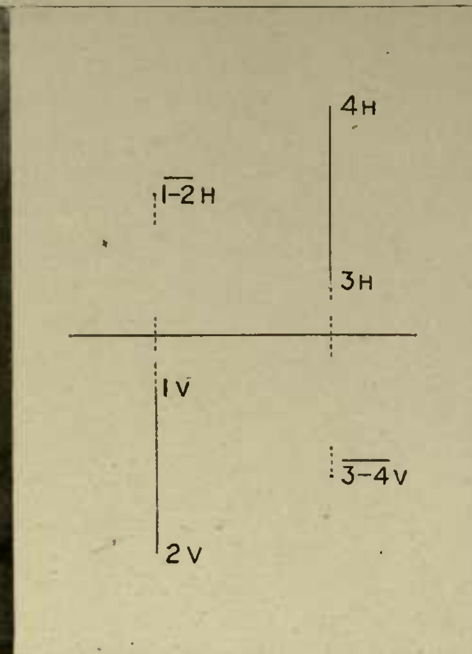


FIG. 41

68. STRAIGHT LINES.—If 1 and 2 are the limiting points (ends) of any straight line $\overline{1–2}$ in space, the lines between 1H and 2H, and between 1V and 2V will be the top view and front view respectively of the line $\overline{1–2}$.

When the views of 1 and 2 on the same plane coincide, the corresponding view of $\overline{1–2}$ will be a point.

69. STRAIGHT LINES PERPENDICULAR TO H OR V.

In Fignre 39, let $\overline{1–2}$ represent a line perpendicular to H and $\overline{3–4}$ a line perpendicular to V. It follows:

That the point $\overline{1–2}$H (Figs. 40, 41) is the top view of 1 and of 2, as well as of every point in the line between 1 and 2. That, likewise, $\overline{3–4}$V is the front view of 3 and of 4, and of every point in the line $\overline{3–4}$. Hence:

(*a*) *A line perpendicular to either plane of projection has for its view on that plane simply a point.*

That the line $\overline{1V\ 2V}$ is the front view of $\overline{1–2}$ (Art. 68). Since 1V and 2V are respectively as far from the ground line as 1 and 2 are from H (Art. 66 *c*), the line $\overline{1V\ 2V} = \overline{1–2}$. Since $\overline{1V\ 2V}$ is parallel to $\overline{1–2}$, it is also perpendicular to the ground line. Likewise $\overline{3H\ 4H} = \overline{3–4}$, and is perpendicular to the ground line. Hence:

(*b*) *A line perpendicular to either plane of projection has for its view on the other plane a straight line perpendicular to the ground line, and equal in length to the line of which it is the projection.*

(*c*) If the line $\overline{1–2}$ is moved up until 1 is in H, 1V will be in the ground line (Art. 66 *d*). If the line $\overline{3–4}$ is brought forward until 3 is in V, 3H will be in the gronnd line.

Hence : *If one end of a line is in either plane of projection, the corresponding end of its view on the other plane will be in the ground line.*

THE DRAWING (*Figures 40, 41*).

(*d*) ILLUSTRATION : Let the line $\overline{1\text{–}2}$ (Fig. 39) be 3″ long, $3\frac{1}{4}$″ behind V, upper end 1″ below H. Then its top view (Fig. 41) will be the point $\overline{1\text{–}2\text{H}}$ (Art. 69 *a*) $3\frac{1}{4}$″ behind the ground line. Its front view will be a line $\overline{1\text{v}\ 2\text{v}}$ 3″ long (Art. 69 *b*) perpendicular to the ground line, 1v being 1″ below it.

If $\overline{3\text{–}4}$ is 3″ long, $3\frac{1}{4}$″ below H, and nearest end 1″ behind V, its front view will be $\overline{3\text{–}4\text{v}}$ $3\frac{1}{4}$″ below the ground line; its top view will be $\overline{3\text{H}\ 4\text{H}}$ 3″ long, 3H being 1″ behind the ground line.

If $\overline{1\text{–}2}$ were no distance behind V, would $\overline{1\text{–}2}$ and $\overline{1\text{v}\ 2\text{v}}$ coincide?

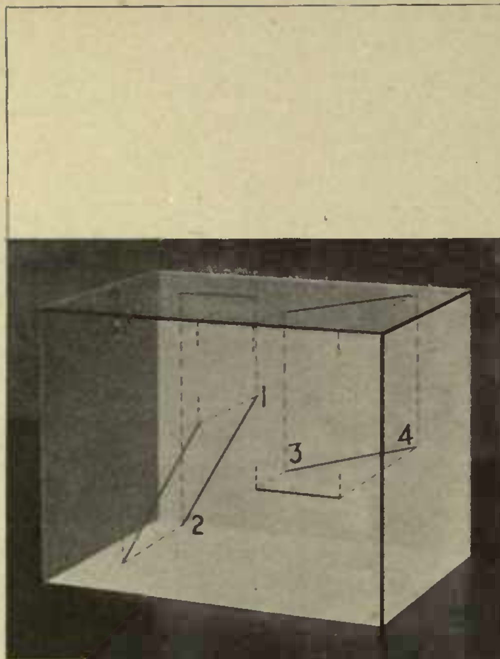


Fig. 42

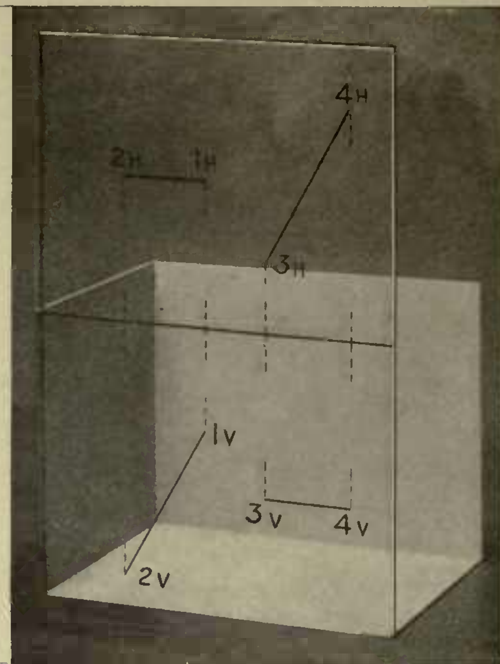


Fig. 43

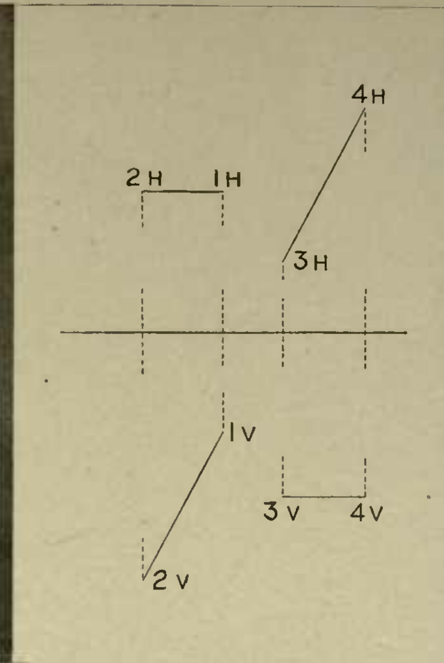


Fig. 44

70. Straight Lines Parallel to One Plane of Projection but at an Angle with the Other.

In Figure 42 let $\overline{2-1}$ represent a line parallel to V but at an angle with H, and $\overline{3-4}$ a line parallel to H but at an angle with V. It follows:

That $\overline{2\text{H}\ 1\text{H}}$ and $\overline{2\text{V}\ 1\text{V}}$ (Figs. 43, 44) are, respectively, the top and front views of $\overline{2-1}$. Since $\overline{2-1}$ is parallel to V, $\overline{2\text{V}\ 1\text{V}}=\overline{2-1}$, and the angle which $\overline{2\text{V}\ 1\text{V}}$ makes with the ground line is equal to the angle which $\overline{2-1}$ makes with H. Likewise, $\overline{3\text{H}\ 4\text{H}}=\overline{3-4}$, and the angle $\overline{3\text{H}\ 4\text{H}}$ makes with the ground line is equal to the angle which $\overline{3-4}$ makes with V. Hence:

(*a*) *When a line is parallel to either plane of projection, its view on that plane represents the true length of the line; and the angle which this view makes with the ground line is equal to the angle which the line in space makes with the plane to which it is not parallel.*

That since 2 and 1 are equal distances from V, 2H and 1H are equal distances from the ground line. Likewise, 3V and 4V are equal distances from the ground line. Hence:

(*b*) *A line parallel to either plane of projection has for its view on the other plane a line parallel to the ground line.*

That since 2 and 1 are not equal distances from H, $\overline{2\text{H}\ 1\text{H}}$ is shorter than $\overline{2-1}$. Likewise, $\overline{3\text{V}\ 4\text{V}}$ is shorter than $\overline{3-4}$. Hence:

(*c*) *When a line is not parallel to a plane of projection, its view on that plane is always shorter than the true length of the line.*

(*d*) If a line lies in either plane of projection, it will coincide with its view on that plane. Where will its other view be? (See Art. 69 *c*.)

THE DRAWING (*Figures 43 and 44*).

(*e*) ILLUSTRATION: Let the line $\overline{2\text{–}1}$ (Fig. 42) be 3″ long, $3\frac{1}{4}$″ behind V, and upper end $1\frac{1}{2}$″ below H. Let it be at an angle of 60° with H. Then its front view, $\overline{2\text{V}\ 1\text{V}}$ (Fig. 44), is 3″ long and makes an angle of 60° with the ground line (Art. 70 *a*). The point 1V is $1\frac{1}{2}$″ below the ground line. Its top view, 2H 1H, is parallel to and $3\frac{1}{4}$″ behind the ground line (Art. 70 *b*). It is less than 3″ long (Art. 70 *c*). Likewise, if $\overline{3\text{–}4}$ is 3″ long, $3\frac{1}{4}$″ below H, makes an angle of 60° with V, nearest point 3 is $1\frac{1}{2}$″ behind V, then: $\overline{3\text{H}\ 4\text{H}}$ is 3″ long and makes an angle of 60° with the ground line. 3H is $1\frac{1}{2}$″ behind the ground line. $\overline{3\text{V}\ 4\text{V}}$ is parallel to and $3\frac{1}{4}$″ below the ground line.

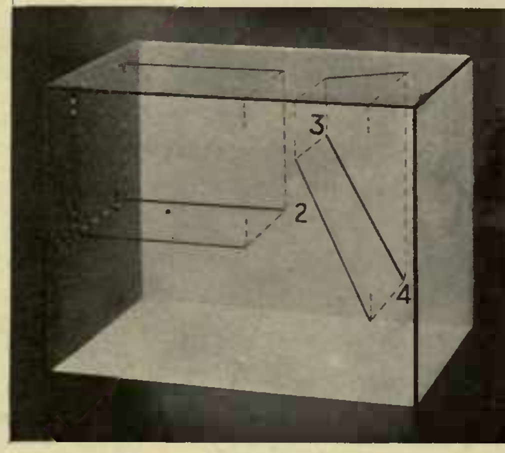


Fig. 45

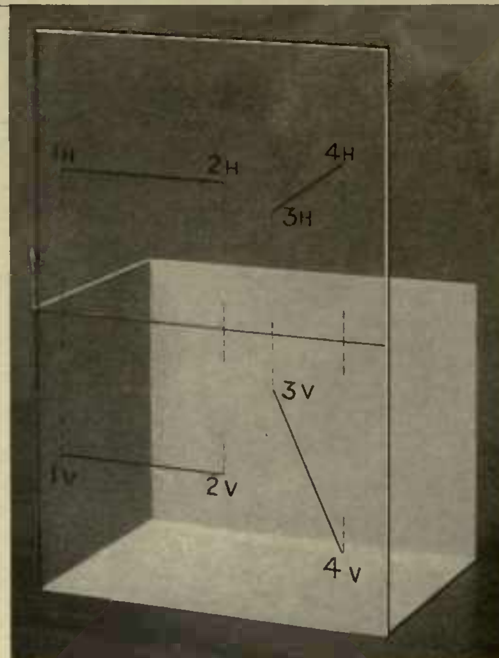


Fig. 46

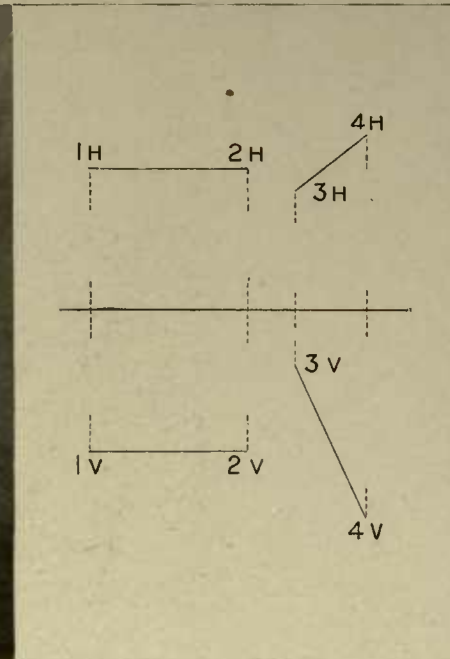


Fig. 47

71. Lines Parallel to Both H and V, and Lines Parallel to Neither H nor V.

In Figure 45, let the line $\overline{1\text{–}2}$ be parallel to both H and V. It is evident then that both $\overline{1\text{V}\ 2\text{V}}$ and $\overline{1\text{H}\ 2\text{H}}$ (Figs. 46 and 47) must both be parallel to the ground line. Hence:

(*a*) *A line parallel to both H and V has for its two views lines parallel to the ground line, both of which are equal in length to the line itself.*

If the two views of a line are parallel to and equal distances from the ground line, what position with respect to H and V does the line in space occupy?

In Figure 45, let the line $\overline{3\text{–}4}$ be parallel to neither H nor V. It is evident then that both $\overline{3\text{V}\ 4\text{V}}$ and $\overline{3\text{H}\ 4\text{H}}$ (Figs. 46 and 47) are shorter than $\overline{3\text{–}4}$ (Art. 70 *c*). Moreover, the angle which $\overline{3\text{V}\ 4\text{V}}$ makes with the ground line is not equal to the angle which $\overline{3\text{–}4}$ makes with H, although it is the front view of $\overline{3\text{–}4}$; neither is the angle which $\overline{3\text{H}\ 4\text{H}}$ makes with the ground line equal to the angle $\overline{3\text{–}4}$ makes with V. Hence:

(*b*) *If a line is parallel to neither plane of projection, both views are shorter than the line itself. The angles which the line makes with the planes of projection are not represented* in their true size *by the angles which the views make with the ground line.*

(*c*) Any two lines, one in H and the other in V, drawn at random but having their corresponding ends in lines perpendicular to the ground line, will be the views of some line of definite length in space.

(*d*) A line of definite length at a fixed angle to either plane of projection may occupy an infinite number of positions in space, but its view on that plane will always be of a constant length.

ILLUSTRATION: Let a line 4″ long at an angle of 60° with H be revolved about a *vertical* axis through any one of its points. In any one of its successive positions the line will make an angle of 60° with H (Why?), and its top view will be 2″ long. (Why?)

72. PROFILE PLANE.—A plane perpendicular to both H and V is called a *profile plane.* A line is in a profile plane when both of its views lie wholly within a line perpendicular to the ground line.

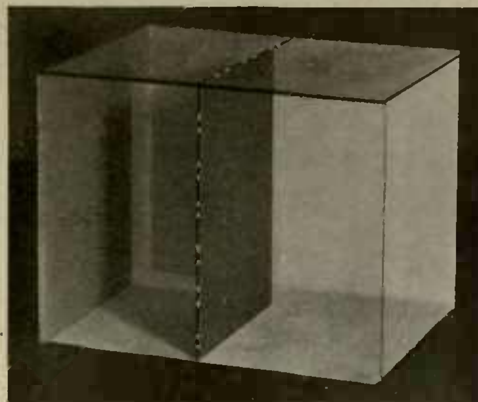


FIG. 48

73. GIVEN: *The two views of a line, neither of which is parallel to the ground line, to find the true length of the line and the angle it makes with either plane of projection.*

The line must be brought parallel to H or V (Art. 70 *a*). For example, let it be brought parallel to V. Revolve the top view (allowing one of its ends to remain fixed) until it is parallel to the ground line. [This is equivalent to revolving the line itself (about a vertical axis through one of its ends) until it is parallel to V. (Why?) (Art. 70 *b*).] The corresponding front view will give the true length of the line, and the actual angle it makes with H.

To find the angle the line makes with V, revolve the front view in a similar manner until it is parallel to the ground line. The corresponding top view not only gives the angle the line makes with V, but also the true length of the line, which should agree with that obtained by the first method.

ILLUSTRATION: In Figure 49, let $\overline{1\text{H}\ 2\text{H}}$ and $\overline{1\text{V}\ 2\text{V}}$ be the views of a line in space. Revolve the top view about 1H to the position $\overline{1\text{H}\ 2\text{H(R)}}$. (Why must the revolved position of the top view be parallel to the ground line?) The point 2V moves in a line parallel to the ground line (Why?) until its revolved position 2V(R) is in a line through 2H(R) perpendicular to the ground line (Why?). $\overline{1\text{V}\ 2\text{V(R)}}$ is the true length of the line $\overline{1\text{–}2}$, and the angle X it makes with the ground line is equal to the angle $\overline{1\text{–}2}$ makes with H.

If the front view $\overline{1\text{V}\ 2\text{V}}$ be revolved in a similar manner until it is parallel to the ground line, the corresponding revolved position of $\overline{1\text{H}\ 2\text{H}}$ will also give the true length of $\overline{1\text{–}2}$, as well as the angle it makes with V. (A check on the first method.)

74. The converse of Article 73 is equally important. GIVEN: *A line of definite length and the angles it makes with H and V, respectively, to find its two views.*

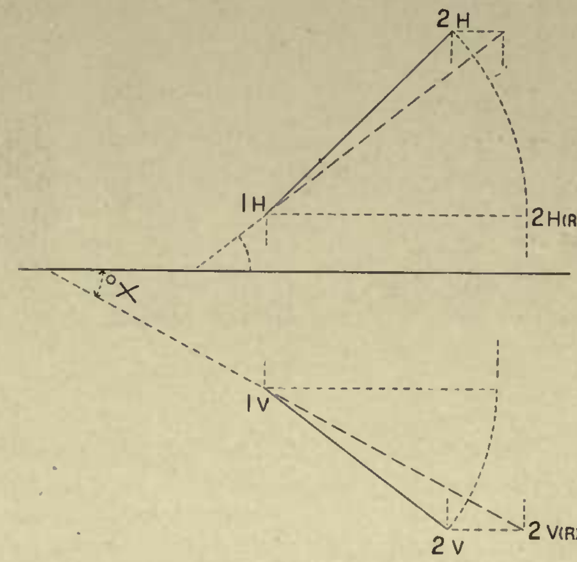


FIG. 49

First draw the two views of the line when it is parallel to one plane of projection and at the given angle with the other. The shorter view must now be revolved (one end remaining fixed) to such a position that the corresponding view on the other plane will be of the right length. (What will be this length? One end of which view will move in a line parallel to the ground line during the revolution?)

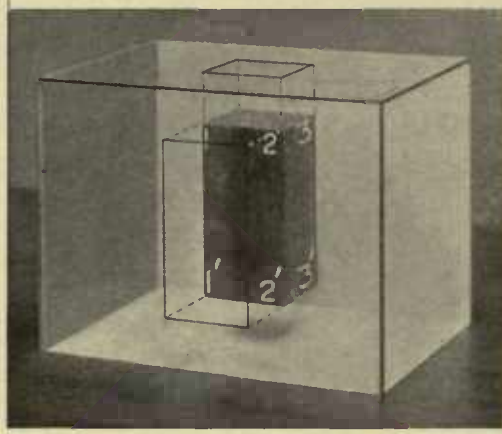


FIG. 50

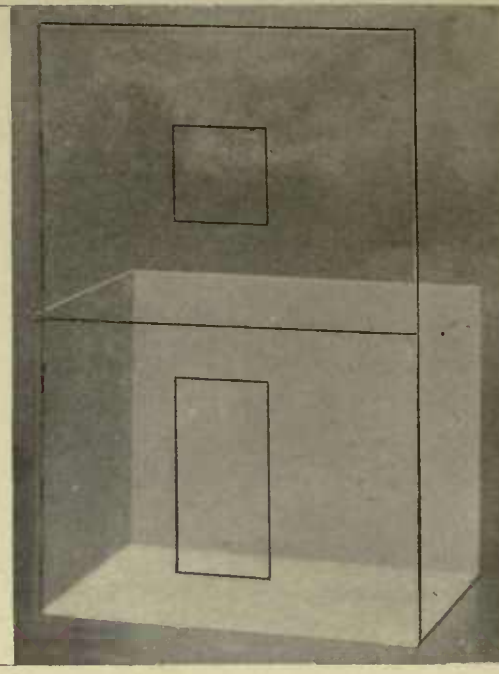


FIG. 51

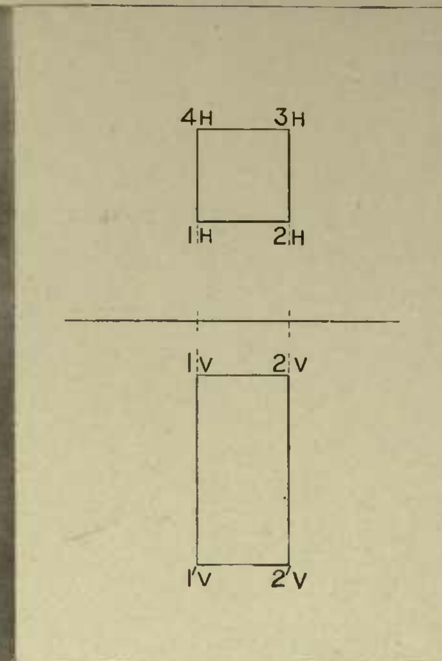


FIG. 52

75. PLANE FIGURES.—A solid bounded by plane surfaces has for its edges straight lines, to any one of which the principles already given may be applied. When two or more edges are taken together additional principles pertaining to plane figures may be deduced.

76. BOUNDARY-LINES AND SURFACES OF SOLIDS.

From Figure 50 it is evident:

That the two vertical edges of the square prism 1–1′ and 2–2′ have for front views two parallel lines. The top view of each is a point.

That the two front views of 2–2′ and 3–3′ would be parallel if 3–3′ were not directly behind 2–2′, thus making the two front views coincident. Hence:

(*a*) *When two lines are parallel in space their corresponding views are parallel, unless these views are coincident or become mere points.*

If two lines in space intersect, their corresponding views will intersect, and a straight line between the two points of intersection will be perpendicular to the ground line.

That the upper base 1 2 3 4, being parallel to H, has for a top view a square equal in size to the base itself. If the base were a hexagon or any other polygon *parallel to H*, the top view would be identical in outline with the base itself. Hence:

(*b*) *Any plane figure parallel to either plane of projection is projected on that plane in its true outline.*

If the plane of an angle formed by two lines intersecting in space is parallel to neither H nor V, the views will always be greater or less than the angle they represent. Any plane figure must be brought parallel to either H or V to ascertain its true outline.

That if the upper base is parallel to H its front view will be a straight line,

representing in reality four lines. Likewise, if the face 2 3 3′ 2′ is perpendicular to both H and V, its top and front views are both straight lines.

(*c*) *When any plane figure is perpendicular to either plane of projection its view on that plane will be a straight line. A plane figure perpendicular to both planes of projection has for each of its views a straight line.*

77. Solids.—Mechanical drawing is mainly used to represent solids. But *solids* are bounded by *surfaces*, which in turn are bounded by *lines*, which are themselves limited by *points*. Views of a solid can therefore be found by drawing the views of its limiting points, lines, and surfaces, according to the principles already given.

78. Square Prism.—Let the prism (Fig. 50) be 2″ square, 4″ high. The upper base is parallel to and 1½″ below H. The front vertical face is parallel to and 2¼″ behind V.

The top view of the prism (Fig. 52), therefore, is a 2″ square, the front side of which is parallel to (Why ?) and 2¼″ behind (Why ?) the ground line. The front view is a 2″ × 4″ rectangle, the upper side of which is parallel to (Why ?) and 1½″ below (Why ?) the ground line.

79. Assuming the Position of an Object.—The prism (Fig. 50) is in such a position, with two faces parallel to V and two bases parallel to H, that the top and front views are very simple. The draftsman usually assumes the faces of the object which he particularly wishes to show parallel to H or V. This, however, is often impossible. Solids are therefore purposely assumed at angles with H and V in many problems in order that the student may learn to represent an object in any position whatever. (See Arts. 83, 84.)

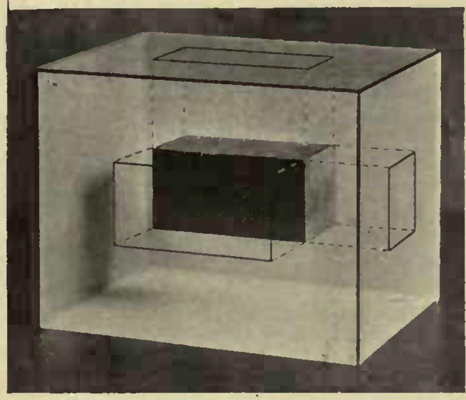


FIG. 53

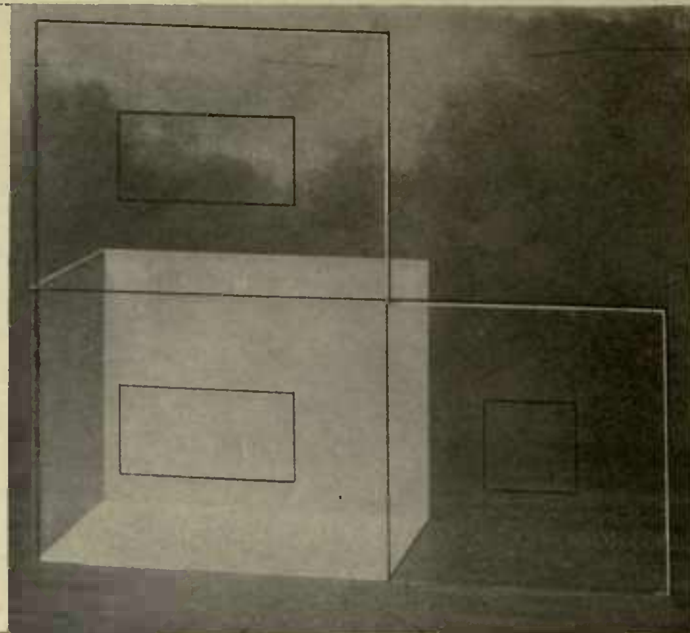


FIG. 54

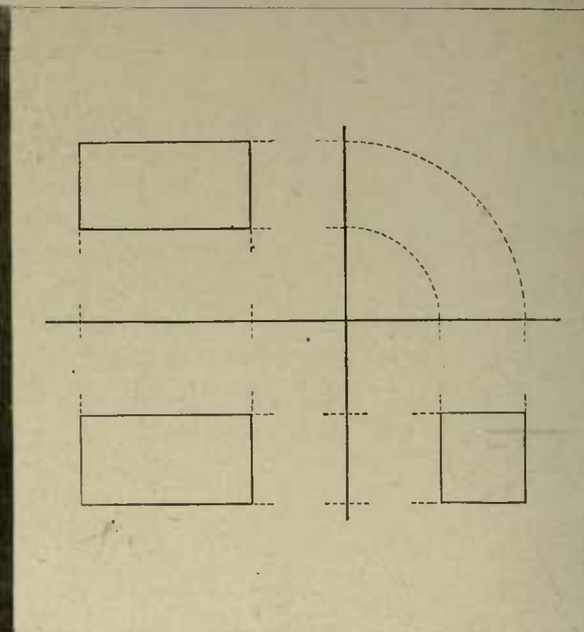


FIG. 55

80. ADDITIONAL VIEWS.—It often happens that the top and front views of an object in a given position do not adequately represent it. For example, the top and front views of a square prism in the position shown in Figure 53 are both rectangles. But the top and front views of the cylinder, Figure 56, are also two similar rectangles. The ends of the rectangles in one case represent squares, in the other case circles, but there is nothing to show this. Something more is needed, then, to determine whether the rectangles themselves are views of a square prism or of a cylinder. Accordingly, *end views* are shown (in Figure 55 a square, in Figure 58 a circle) which remove all doubt.

81. (*a*) THE PRISM, FIGURE 53.

Let the prism (Fig. 53) be 2″ square, 4″ long, with its top face parallel to and $2\frac{1}{4}''$ below H, its front face parallel to and $2\frac{1}{4}''$ behind V, and its end $2\frac{1}{2}''$ from E (the end plane of projection). The top and front views are obtained in the usual manner. The end view is obtained in precisely the same way as the other two views, except that V and E are used instead of H and V. This view will therefore be a 2″ square, since the end of the prism is parallel to E. The end plane is revolved about its intersection with V (a vertical ground line) when the three planes are brought into one, as shown in Figure 54. In Figure 55 the end view will therefore be projected across (horizontally) from the front view, and the clear space between the two views will be $2\frac{1}{4}''+2\frac{1}{2}''=4\frac{3}{4}''$. If a vertical ground line is drawn, it will be $2\frac{1}{2}''$ from the front view and $2\frac{1}{4}''$ from the end view. (Why?)

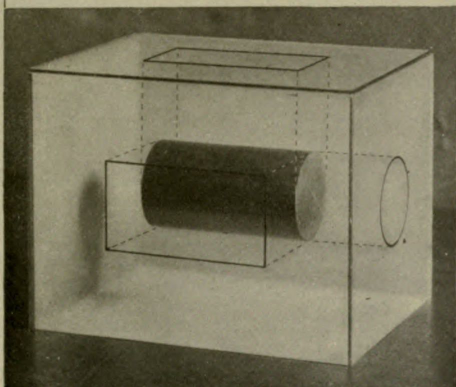


FIG. 56

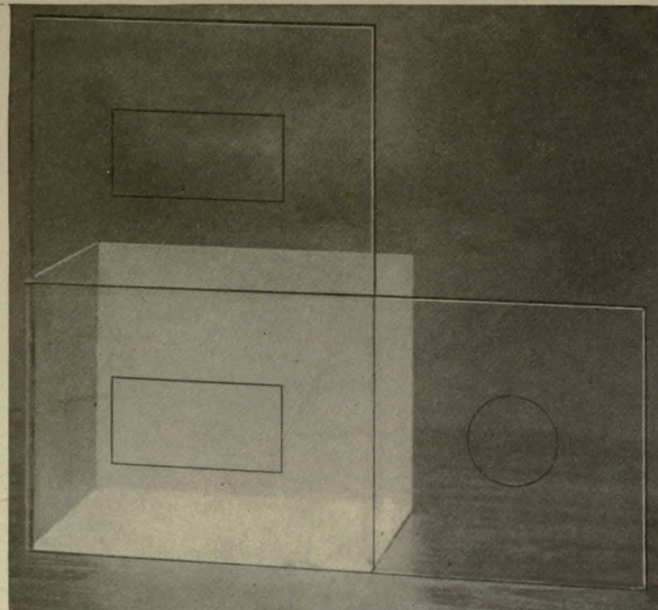


FIG. 57

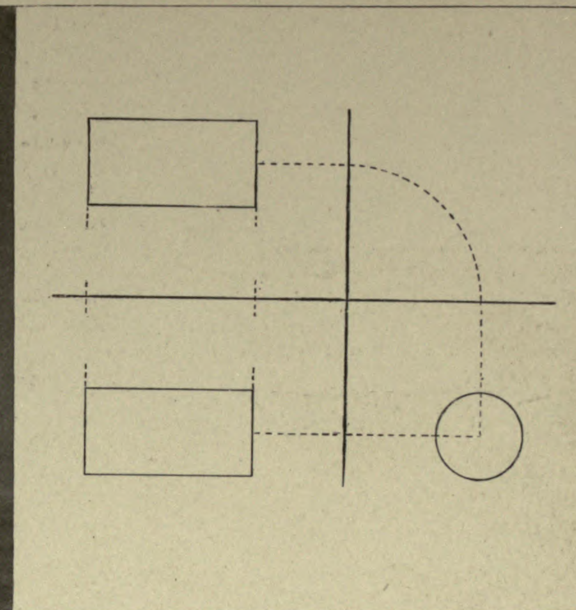


FIG. 58

(*b*) THE CYLINDER, FIGURE 56.

Let the cylinder (Fig. 56) be 2″ in diameter and 4″ long, with its axis parallel to and $3\frac{1}{4}$″ from both H and V. The end of the cylinder is $2\frac{1}{2}$″ from E. The end view (Fig. 58) is a circle, the centre of which is on a horizontal line through the centre of the rectangle (front view) and $2\frac{1}{2}'' + 3\frac{1}{4}'' = 5\frac{3}{4}''$ away from the end of this rectangle. (Why?)

(*c*) In general: *The front and end views of any point lie in the same horizontal line—i. e., a line at right angles to a vertical ground line.* In a similar way all the principles relating to points and lines when H and V are used can be easily modified to apply to V and E or H and E.

It is often more consistent to call the view on E a *side view* instead of end view. (See Art. 84.)

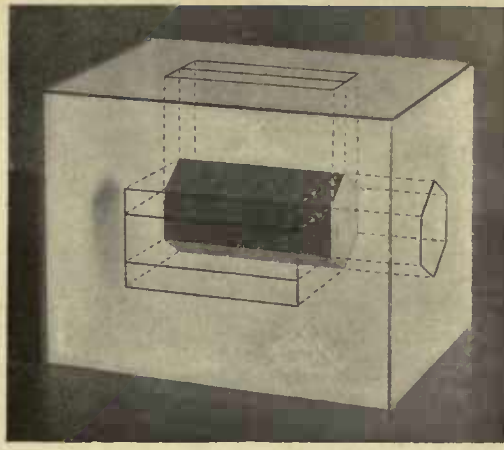


Fig. 59

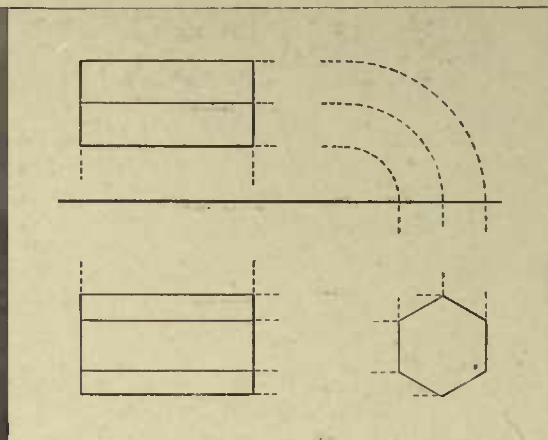


Fig. 60

(*d*) The Hexagonal Prism, Figure 59.

The hexagonal prism (Fig. 59) is another illustration of the necessity of adding an end view. In the orthographic drawing (Fig. 60) the end view is drawn first in its proper position and the other two views derived from it as indicated.

82. The Hexagonal Pyramid, Figure 61.

Let the pyramid (Fig. 61) have its base parallel to H. Let its altitude be 4″ and a side of the base 1″ long. The top view of the pyramid (Fig. 62) will be a true hexagon, one side of which is 1″ long (Art. 76 *b*). The diagonals of this hexagon should not be thought of as diagonals at all, but as *views of edges* which run from the vertex to each corner of the base. In the front view the base is represented by a straight line (Art. 76 *c*). Since the altitude of the pyramid is parallel to V, its true length, 4″, can be measured above the centre of the base, in the front view, to find the point representing the vertex.

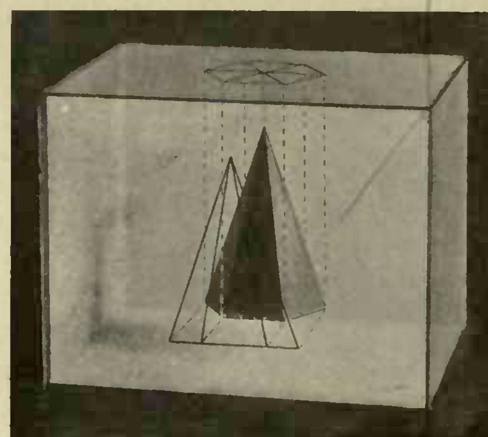


Fig. 61

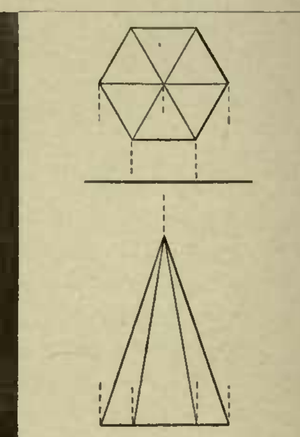


Fig. 62

83. Invisible Edges.—When a portion of a solid is between one of its edges and a plane of projection, the view of the edge on that plane is invisible. Invisible edges are represented by broken lines. (See Art. 32 *a.*)

Illustration: The prism (Fig. 63) has been so placed with respect to V that the rear edges are not directly behind the front edges. One of these rear edges is visible in the front view, the other is invisible and is represented by a broken line. In the side view the edge farthest from E is invisible.

Invisible edges are usually shown when the drawing is made clearer thereby, otherwise they may be omitted.

84. The Square Prism of Figure 63.

Let the prism of Figure 50 be turned until the front face, instead of being parallel to V, makes an angle of say 30° with V (Fig. 63). The dotted lines (which are in reality *projecting lines*) indicate how the front and side views can be derived from the top view. In the orthographic drawing (Fig. 64) it is therefore necessary to draw the top view first. This top view will be a square, since the base of the prism is still parallel to H, but the side of the square which represents the top view of the front face (Art. 76 *c*) makes an angle of 30° with the ground-line. (Why?) The nearest corner of the square is as far behind the ground line as the nearest edge of the prism is behind V. (Why?) The *front view* of any point or edge can be found by drawing a line at right angles to the ground line through the top view of the same point or edge (Why?), and laying off on this line the proper measurements below the ground line. (What will the proper measurements correspond to?) The work is indicated by the projecting lines (Fig. 64).

Remark: When in doubt as to which view of an object to draw first, select that one which shows a base, face, or end of the object in its true outline, *i.e.*, the view on that plane of projection to which part of the object is parallel.

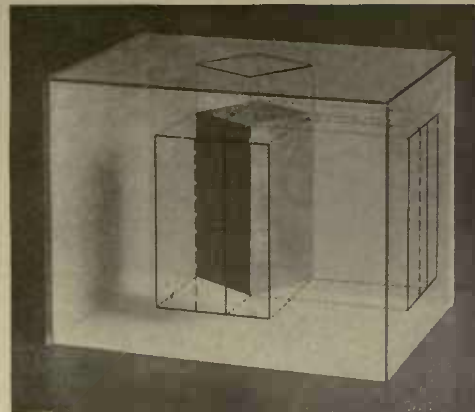


Fig. 63

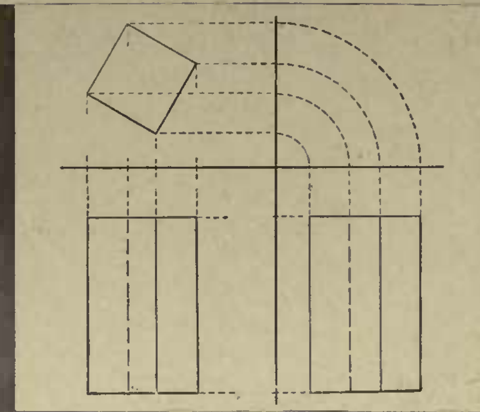


Fig. 64

85. A Solid Inclined to H and V.—(*a*) When a solid is inclined to both H and V, it is in the most difficult position to draw in which it is possible to place it. The process consists of three steps: (1) The solid is assumed in some simple position with respect to H and V, and a drawing made of it in this position. (2) The solid is tipped with respect to *one* plane, but its position with respect to the other plane remains unchanged. (3) The solid is tipped with respect to the plane to which it has not yet been inclined, but its position with respect to the other plane is the same as it was at the end of the second step of the process. The views of the solid in this third position are the ones required. These views are, in part, derived from those of the second step, which are in turn derived from the views of the solid in its first position.

Note: To avoid confusion, it is well to assume that each time the solid is tipped it is also moved far enough to the right or left to enable a separate pair of views to be drawn for each of its three positions. (See page 62.) This is not essential, however, for the three pairs of views can be drawn in the same place on the paper, the views of the solid in its first two positions serving as so many construction lines which may be afterwards erased. The latter arrangement is often made necessary by the limited amount of space available. The method of determining the views is practically the same, no matter which arrangement is adopted.

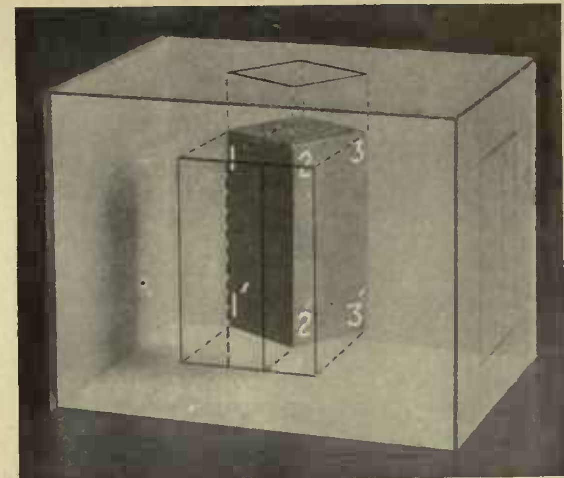


Fig. 65

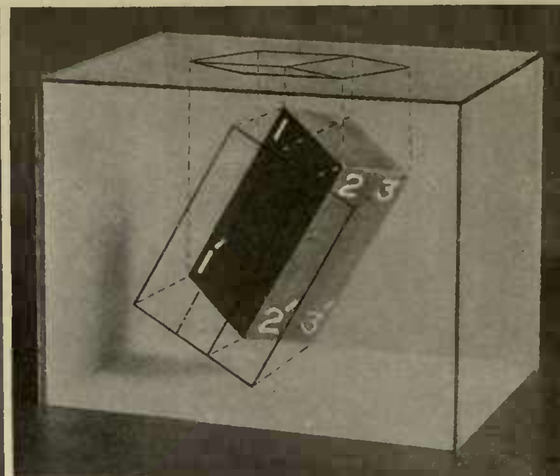


Fig. 66

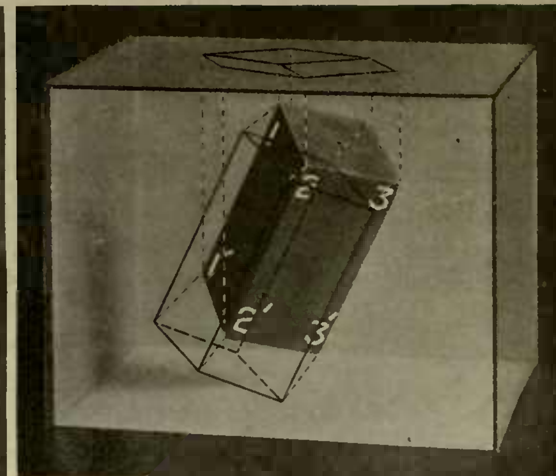


Fig. 67

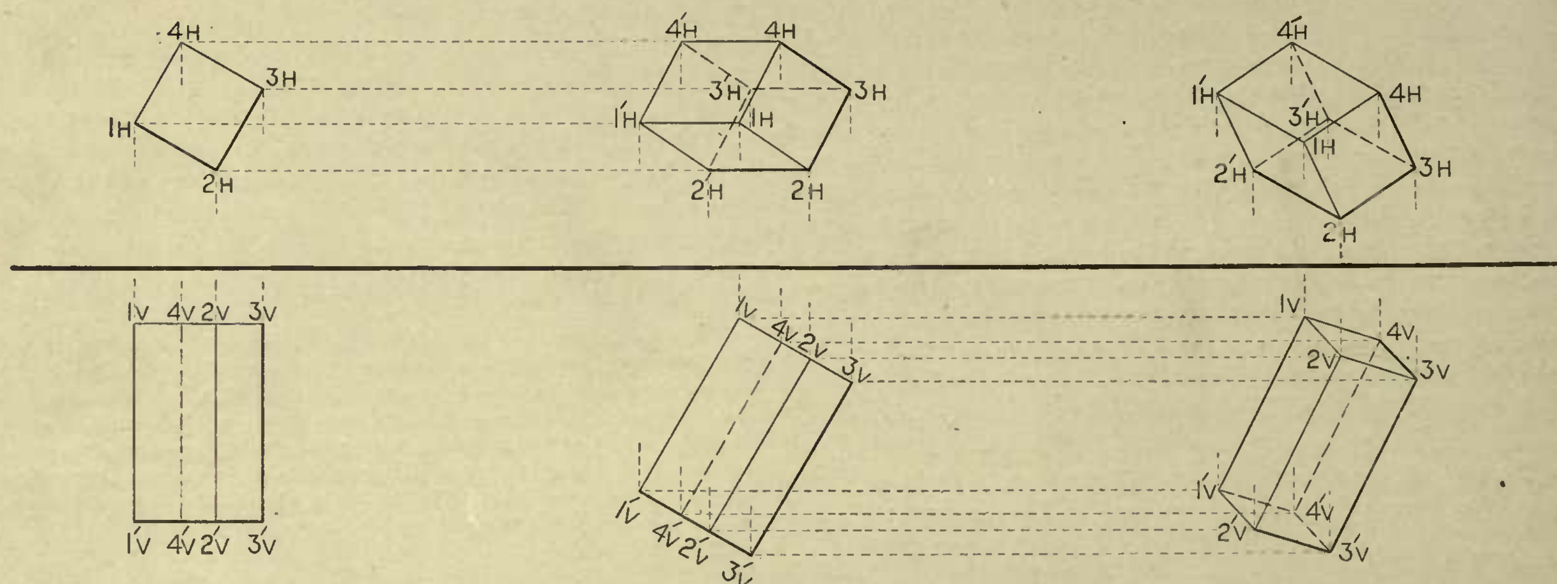


Fig. 68

Fig. 69

Fig. 70

(b) ILLUSTRATION: SQUARE PRISM INCLINED TO H AND V.

FIRST POSITION.

The position of the prism with respect to H and V in Figure 65 is the same as that of Figure 63, page 61. Hence the corresponding orthographic drawing Figure 68 is exactly like that of Figure 64, page 61, except the side view has been omitted.

SECOND POSITION.

In Figure 66 the prism is tipped up until the plane of the upper base makes an angle with H (any desired angle), *but the position of the prism with respect to V has not been changed;* that is, every point of the prism is just as far behind V in Figure 66 as it is in Figure 65. Hence: (1) The front view (Fig. 69) is the same *in outline* as the front view of Figure 68, but it is tipped until the upper line makes the same angle with the ground line that the plane of the upper base makes with H.

(2) Since in tipping the prism (and moving it to the right) every point of it was moved parallel to V, the *top view* of any particular point is as far behind the ground line in Figure 69 as in Figure 68—i. e., its path during the change of position of the prism was a line parallel to the ground line.

(c) The actual work of drawing is as follows: (1) At any convenient distance to the right, copy the front view of Figure 68, but incline it at the desired angle to the ground line. (See 1, above.) In this case the line 1v 4v 2v 3v, representing the front view of the upper base, is drawn at 30° to the ground line, since the upper base makes an angle of 30° with H.

(2) Through the principal points in the top view of Figure 68, draw lines to the right parallel to the ground line. The corresponding points in the top view, Figure 69, will lie somewhere in these lines. (See 2, above.)

(3) Through any point in the front view of Figure 69, as 3v, draw a line at right angles to the ground line. The point 3H (Fig. 69) will be at the intersection of this line and the line parallel to the ground line through 3H (Fig. 68). In a similar manner draw lines perpendicular to the ground line through each of the principal points of the front view (Fig. 69), and find the intersection of each of these lines with the line through the corresponding point of the top view (Fig. 68) parallel to the ground line.

(4) Between the points thus found draw (1) all the visible edges, and then (2) the invisible edges, if they are to be shown.

(d) In more complicated figures it is difficult to connect the proper points in the top view unless they have been systematically kept track of. It will save time to number or letter the principal points of the first figure and use the same notation for the corresponding points in the second figure, *marking each point as soon as found.* For example, if the corners of the upper base (top view, Fig. 68) are lettered around in order—1H, 2H, 3H, and 4H—then 1H, 2H, 3H, and 4H of the new top view (Fig. 69) may be joined in order, and these lines, being in the upper base, will all be visible. The corners of the lower base should be distinguished in some way from those of the upper base. A good way is to let 1′ be the corner under 1, 2′ under 2, and so on, as shown in the figure. Then 1′H, 2′H, 3′H, and 4′H can be joined in order, but $\overline{2'\text{H}\ 3'\text{H}}$ and $\overline{3'\text{H}\ 4'\text{H}}$ will be invisible. Likewise, corresponding points of the upper and lower bases, as 1H and 1′H, 2H and 2′H, etc., may be joined, since these lines will represent the top views of the corresponding edges.

(e) All lines in the *perimeter* of any top view are always visible. These can be drawn first. A line within this perimeter is invisible when from the front view it is seen to be underneath any portion of the solid (Art. 83).

THIRD OR FINAL POSITION.

(f) The position of the prism Figure 67 with respect to H is the same as that of the prism Figure 66. The vertical edges, however, instead of being parallel to V, are now inclined to V. Note that:

(1) The top view (Fig. 70) must be the same *in outline* as the top view of Figure 69. (Why?)

(2) Every point in the new front view (Fig. 70) must be as far below the ground line as the corresponding point in the front view Figure 69. (Why?)

(g) The actual work of drawing is as follows: (1) At any convenient distance to the right, copy the top view of Figure 69, but incline it at the desired angle to the ground line. [If in the final position of the prism a vertical edge makes an angle say of say 60° with V, how can one find the angle which the line representing this edge in the top view makes with the ground line.] (See Art. 74.)

(2) Through the principal points in the front view (Fig. 69) draw lines parallel to the ground line. (Why?)

(3) Draw lines through each of the principal points of the top view (Fig. 70) perpendicular to the ground line, and find the intersection of each of these lines with a line through the corresponding point of the front view (Fig. 69) parallel to the ground line. [For example, a line through 3H (Fig. 70) perpendicular to the ground line intersects a line parallel to the ground line through what point of the front view?] (Fig. 69).

(4) Between the points thus found draw (1) the visible and (2) the invisible edges.

(h) All lines in the perimeter of the new front view are visible. A line within this perimeter is invisible when from the top view it is seen to lie behind any portion of the solid.

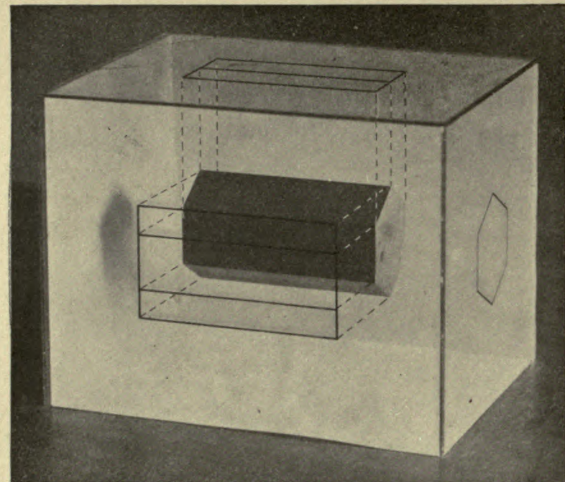


Fig. 71

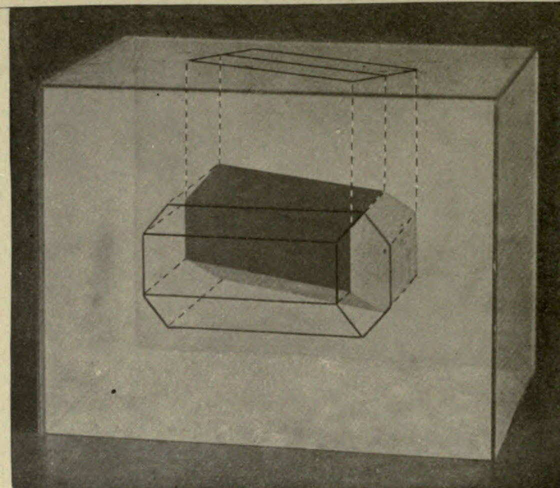


Fig. 72

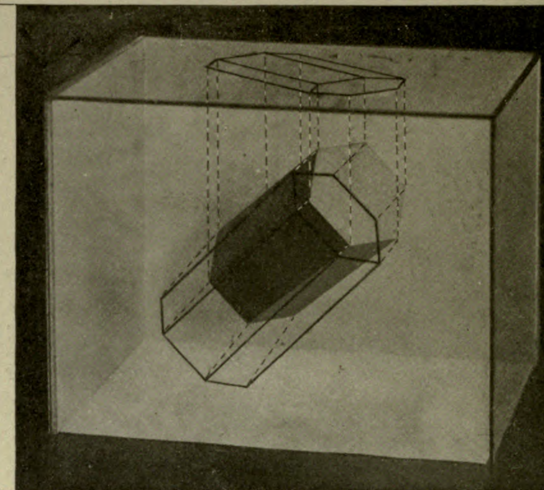


Fig. 73

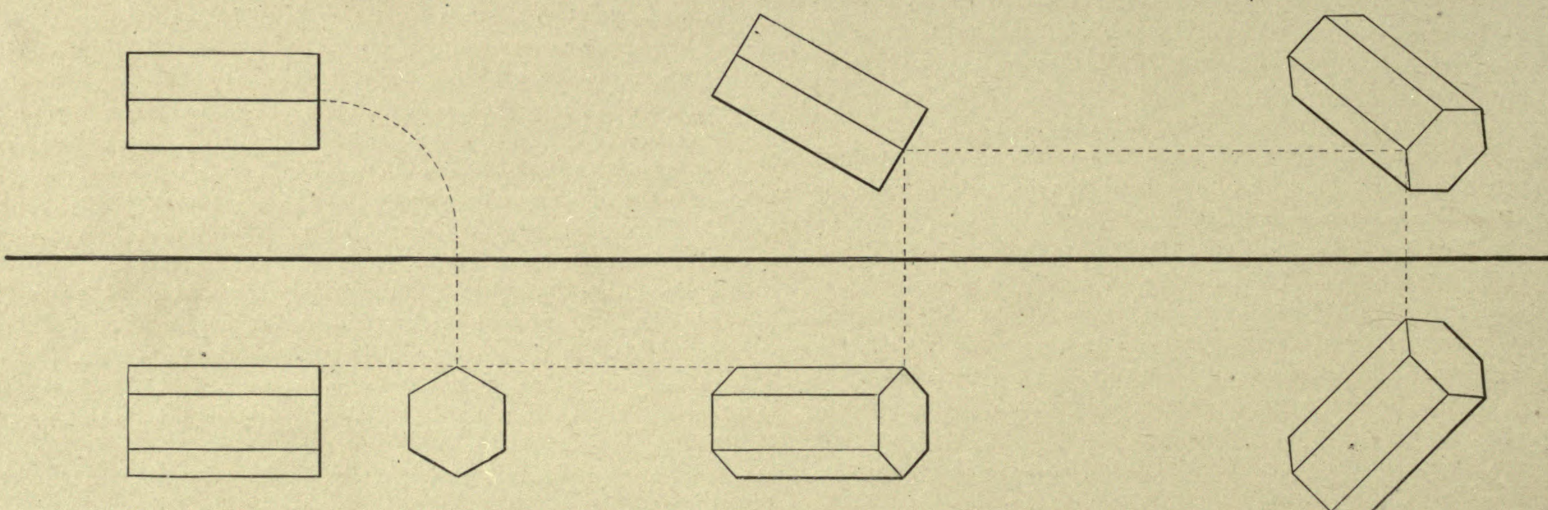


Fig. 74

Fig. 75

Fig. 76

(*b*) Illustration: Hexagonal Prism Inclined to H and V.

A solid may be tipped first with respect to V and then with respect to H. The final result will be the same, no matter to which plane the solid is first inclined. In Figures 71 and 74, for example, a hexagonal prism has its axis parallel to both H and V. In Figures 72 and 75 this axis has been inclined to V (instead of H), but it is still parallel to H. The top view of the prism is therefore the same as before, except that it is turned with respect to the ground line. The new front view, Figure 75, however, must be derived from the front view, Figure 74, and the top view, Figure 75.

The third and final position of the prism is shown in Figures 73 and 76. Here the front view is the same *in outline* as in Figure 75, the position of the prism with respect to V not having been changed from that of Figure 75. The axis of the prism, however, is now inclined to H; hence the new top view, Figure 76, must be derived from the top view, Figure 75, and the front view, Figure 76. In the figures referred to, a single point of the prism can be traced through the different steps of the process by means of the broken construction lines. Invisible edges are purposely omitted in the drawing.

No matter how complicated the position of an object with respect to the planes of projection may be, by assuming the object in a simple position, and then tipping it first with respect to one plane and then the other, according to the process just described, the two views of the object are easily found. It requires considerable care, however, in projecting points from one figure to another if extreme accuracy is to be attained.

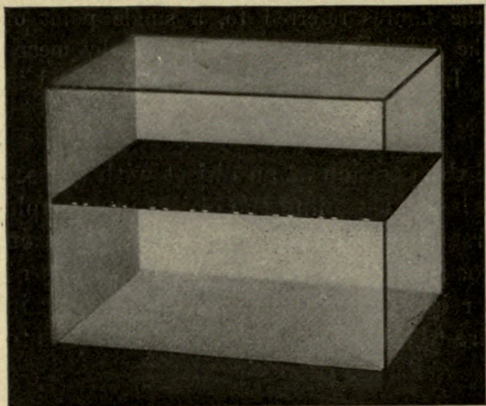


Fig. 77

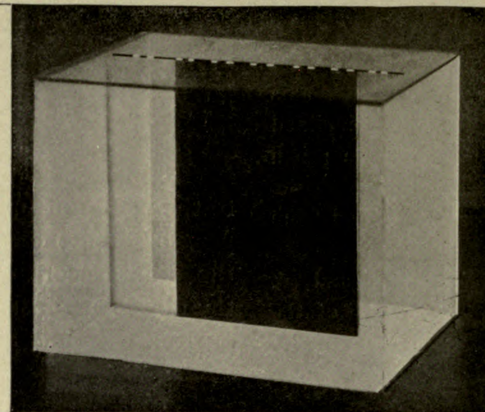


Fig. 78

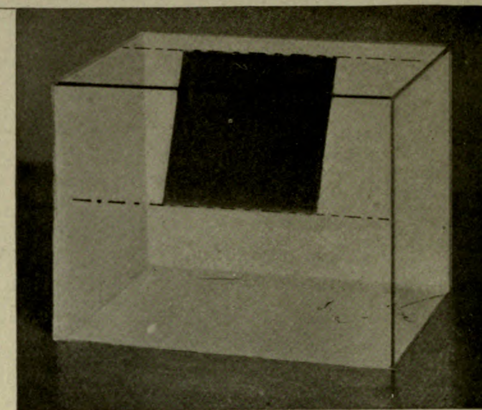


Fig. 79

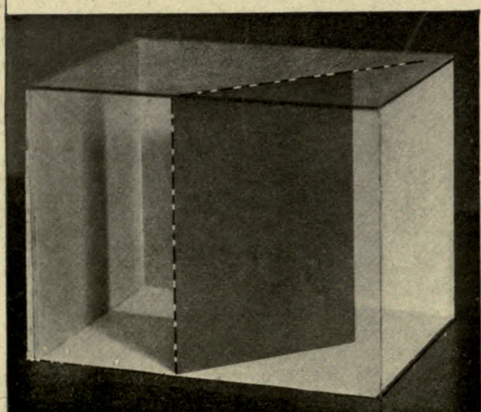


Fig. 80

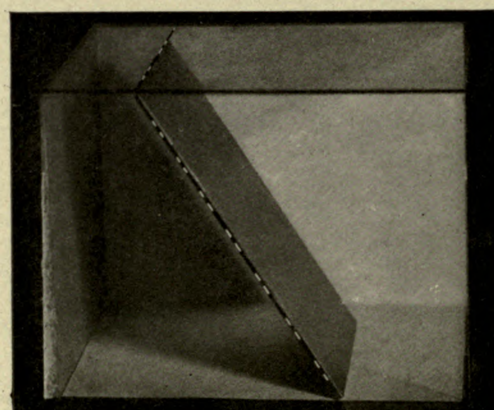


Fig. 81

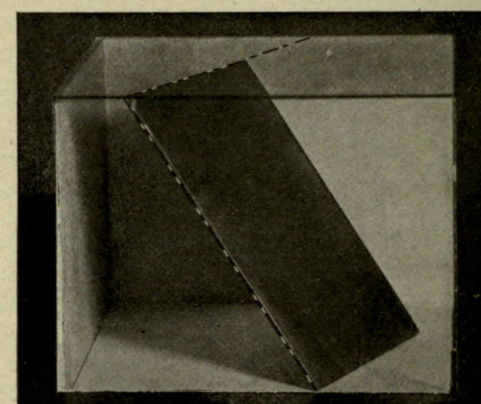


Fig. 82

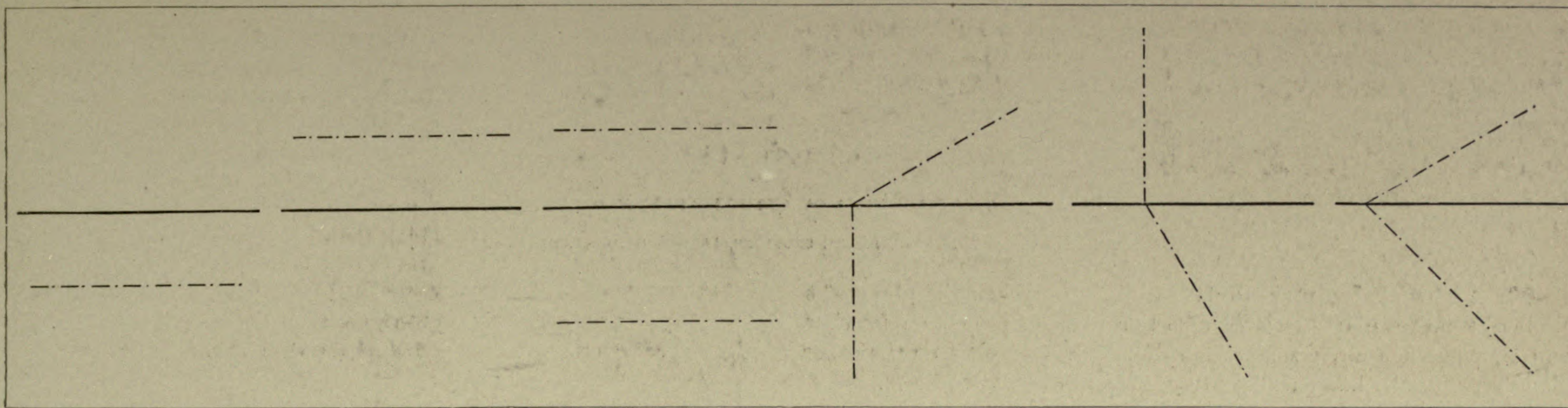


FIG. 83 FIG. 84 FIG. 85 FIG. 86 FIG. 87 FIG. 88

86. PLANES.—The line in which any plane intersects H is called the *horizontal trace* of that plane; its *vertical trace* is the line in which it intersects V.

From the figures it is evident that:

(*a*) A plane parallel to either H or V has but one trace, and that trace is parallel to the ground line (Figs. 77, 78, 83, 84).

(*b*) When a plane is parallel to the ground line its traces are parallel to the ground line (Figs. 79, 85). If a plane is not parallel to the ground line and has two traces, these traces will meet in the ground line. (Why?)

(*c*) A plane perpendicular to H has its vertical trace perpendicular to the ground line (Figs. 80, 86). The horizontal trace of a plane perpendicular to V is perpendicular to the ground line (Figs. 81, 87).

(*d*) If a plane is perpendicular to H, but makes an angle with V, this angle is equal to the angle made by the horizontal trace with the ground line (Figs. 80, 86). If a plane is perpendicular to V, but makes an angle with H, this angle is equal to that between the vertical trace and the ground line (Figs. 81, 87).

(*e*) Each of the traces of a plane oblique to both H and V is at an angle with the ground line, but the angles thus shown are not equal to the angles which the plane makes with H and V (Figs. 82, 88).

(*f*) A plane perpendicular to both H and V is called a *profile plane;* its traces lie in the same straight line perpendicular to the ground line (Fig. 48, page 55).

A trace of a plane is represented by a dot and a dash alternating. (See Art. 32 *d*.)

CHAPTER VI

SPECIAL APPLICATIONS OF ORTHOGRAPHIC PROJECTION

SURFACES OF REVOLUTION, PLANE SECTIONS, INTERSECTIONS, AND SHADOWS

87. A CIRCLE INCLINED TO H AND V.—(*a*) When the plane of a circle of x inches diameter is parallel to a plane of projection, its view on that plane is a circle x inches in diameter. Its view on the other plane is a straight line parallel to the ground line (Art. 76 *b*, *c*).

(*b*) When the plane of a circle is not parallel or perpendicular to a plane of projection, its view on that plane is an ellipse.

(*c*) Let it be required to find the views of a circle, the plane of which is neither parallel nor perpendicular to H or V.

First Method.—(1) Assume the circle parallel to one of the planes of projection, and draw the top and front views of it in this position. (2) Keep it perpendicular to one plane, but incline it to the other, and find the new top and front views (second step, Art. 85). (3) Incline the plane of the circle to the plane of projection, to which it has been kept perpendicular in (1) and (2) (third step, Art. 85).

ILLUSTRATION: (1) Assume the circle Figure 89 parallel to H. Its top view is a circle. Its front view is a straight line. On the circumference of the circle assume any number of points. (These points may be assumed, for example, about 30° of arc apart. Each point will have two views, which may be numbered and lettered in the usual way.)

(2) In Figure 90 the circle has been kept perpendicular to V, but inclined to H. The points in the new top view (Fig. 90) corresponding to the points assumed in Figure 89 are easily found by the method explained in the second step of the process (Art. 85). This new top view will be an ellipse (Art. 87 *b*), plotted by means of the points just found.

(3) In Figure 91 the angle which the plane of the circle makes with H is the same as in Figure 90, but it has now been inclined to V. The new top view (Fig. 91) is exactly like the top view of Figure 90, but turned with respect to the ground line. (The angle which the major axis, for example, makes with the ground line depends on the angle which the plane of the circle makes with V.) The new front view (Fig. 91) is an ellipse found by points derived from corresponding points in the front view (Fig. 90) and the top view (Fig. 91) (third step, Art. 85).

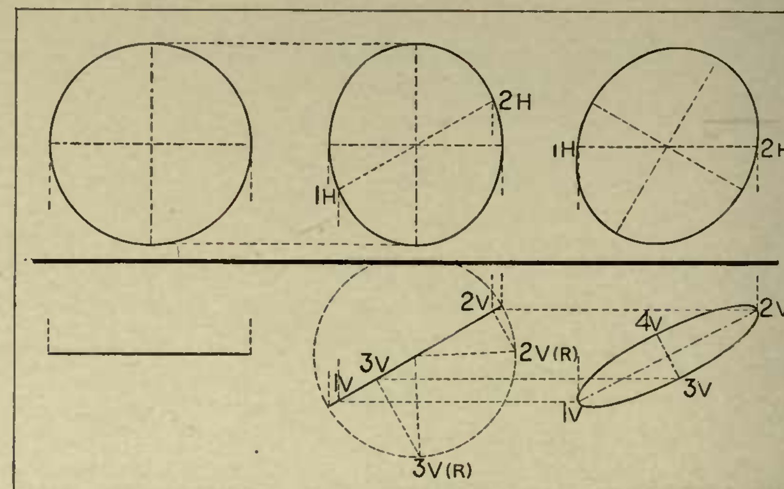


FIG. 89 FIG. 90 FIG. 91

REMARK: This method is general, and may be applied to any curve or irregular figure. Note that the major axis of an ellipse which is a view of a circle, is always equal in length to the diameter of the circle. (Why?)

Second Method.—In the case of a circle, a much shorter method than that given above is to assume but four points in a figure such that the corresponding points of the succeeding figure will be the ends of the major and minor axes of the required ellipse.

ILLUSTRATION: The ends of the axes in the top view (Fig. 90) correspond respectively to the extreme top and bottom points and the extreme left and right points of the circle (top view, Fig. 89). To find the axes of the ellipse in the front view (Fig. 91) is more difficult. The method is as follows: The line $\overline{1\text{H}\ 2\text{H}}$ (Fig. 91) is the top view of that particular diameter of the circle which is parallel to V. (Why?) Hence the corresponding front view $\overline{1\text{v}\ 2\text{v}}$ (Fig. 91) will equal the true length of the diameter of the circle. $\overline{1\text{v}\ 2\text{v}}$ is the major axis of the ellipse. To find the points 1v and 2v (Fig. 91), find by measurement 1H and 2H (Fig. 90), then 1v and 2v (Fig. 90), and project across from the front view (Fig. 90) and down from the top view (Fig. 91), as indicated.

The ends of the minor axis 3v and 4v (Fig. 91) are found as follows: In the front view (Fig. 90) revolve the circle about a diameter parallel to V until the circle is parallel to V. The broken circle is the view of the circle in this position. The point 2v will move to 2v(R). (Why?) The point 3v(R) is 90° of arc from 2v(R). Revolve the circle back and 3v(R) moves to 3v. 3v is 90° from 2v, and hence must be one end of that particular diameter of the circle perpendicular to the diameter $\overline{1\text{–}2}$. Hence if 3v is projected across to the front view (Fig. 91) on to a line perpendicular to and bisecting $\overline{1\text{v}\ 2\text{v}}$ (Fig. 91), the new 3v (Fig. 91) is an end of the minor axis. 4v is an equal distance the other side of the intersection of the two axes.

88. SURFACES OF REVOLUTION.—The views of a *cylinder*, the axis of which is perpendicular to H or V, are a circle and a rectangle.

The views of a *cone*, the axis of which is perpendicular to H or V, are a circle and a triangle.

If the axis of a cylinder or cone is parallel to neither H nor V, a circular base is projected in an ellipse (Art. 87).

Cylinders, cones, and other similar solids are assumed as *right* solids, unless it is otherwise specified.

Any view of a sphere is a circle equal in diameter to a great circle of the sphere.

89. Given: *One view of a point on a surface of revolution to find the other view.*

(*a*) *General Method:* Every point in a surface of revolution must lie in some one element (straight line or a circle) of that surface. Let the top view of a point be given. Through this view draw a top view of the element in which the point lies. Find the front view of the same element. The front view of the given point will lie in the front view of the element, and the line joining the two views of the point must be perpendicular to the ground line (Art. 67 *b*).

If the front view of a point were given, how would the top view be found?

(*b*) ILLUSTRATION: *Cylinder.*—Let 1H (Fig. 92) be the top view of a point 1 on the surface of a cylinder. Required 1v. $\overline{2\text{H}\ 3\text{H}}$ is the top view of the element through the point 1. This element intersects the circumference of the right-hand base in 3H. The circumference appears as a straight line, but if it is revolved to the position indicated by the broken circle, 3H will move to 3′. It is now seen that the element intersects the circumference a distance X above the horizontal diameter *aa*, of which *a*H *a*H is the top view and the point *aa*v the front view.

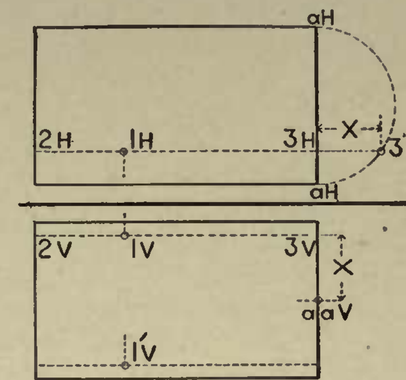


FIG. 92

Therefore 3v must be a distance X above *aa*v on the front view of the circumference. $\overline{2\text{v}\ 3\text{v}}$ is then the front view of the element, and 1v, the required view, is on $\overline{2\text{v}\ 3\text{v}}$, as indicated in the figure.

The line $\overline{2\text{H}\ 3\text{H}}$ is also the top view of another element directly beneath 2–3, and as far below the diameter *aa* as 2–3 is above it. 1H could therefore be the top view of another point, of which 1′v is the front view.

QUESTION: How would the top view 1H be found if the front view 1v were given?

ILLUSTRATION: *Cone.*—Let 1v be the front view of a point 1 on the surface of a cone. Required 1H.

(*c*) *First Method* (Fig. 93): The cone can be conceived as made up of an infinite number of circles, from one of zero diameter at the vertex to one of *aa* diameter at the base. The particular circumference in which the point 1 must lie is of the diameter *bb*. The top view of this circle is found as indicated, and 1H is the required point.

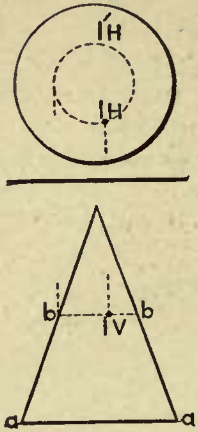


Fig 93

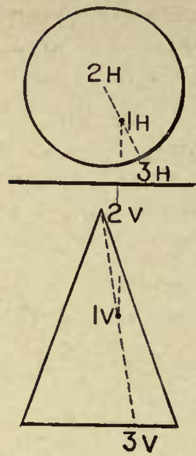


Fig. 94

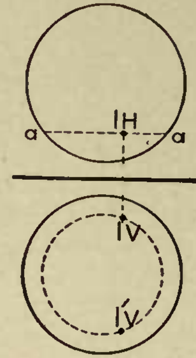


Fig. 95

(*d*) *Second Method* (Fig. 94): The front view of the particular element of the cone in which 1 must lie is $\overline{2\text{v}\,3\text{v}}$. The top view of this element is found as indicated in the figure, the position of 1H is then evident.

Question: How would 1v be found if 1H were given in either of the above examples?

1v is the front view of another point on the surface of the cone directly behind 1, the top view of which is 1'H (Fig. 93).

(*e*) Illustration: *Sphere* (Fig. 69).—Let 1H be the top view of a point on the surface of a sphere. Required 1v. The sphere can be conceived as made up of an infinite number of circles, increasing from zero diameter in front to the diameter of the sphere at the centre, and decreasing to zero diameter again at the extreme rear. The diameter of the particular circumference in which the point 1 must lie is equal to *aa*. There can be only one circle of this diameter in the front view, and 1v must be on its circumference, as shown in the figure.

1H is the top view of another point on the surface of the sphere directly beneath 1. 1'v is the front view of this point.

Solve the problem by conceiving the circles of different diameters, all perpendicular to the vertical axis of the sphere.

Find 1H when 1v is given.

PLANE SECTIONS.

90. When an object is cut by an imaginary plane and the portion cut is shown in a separate view, the latter is called a *section view*.

Section views are useful in showing the invisible parts of an object when broken lines fail to make the drawing clear. For example: a hollow object having something within which it is necessary to show can be conceived as cut in two by a plane, and part of the shell removed, leaving the interior in full view. Section views are often drawn in place of an end, side, top, or bottom view. The portion of the object cut should be section-lined. (See Art. 39.)

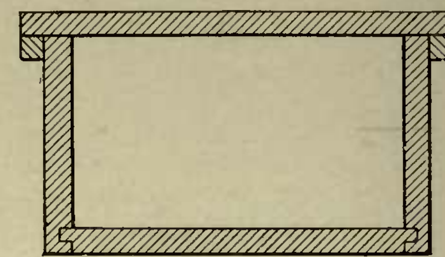


Fig 96

Illustration: The section view of a box (Fig. 96) shows how the bottom of the box is set into the sides and how the top laps over. This would be shown in an end view, but not quite as clearly. The cutting-plane was assumed parallel to the end of the box.

91. Cylinder.—*Axis Parallel to H and V; Cutting-plane Parallel to V* (Figs. 97, 98).

The plane is assumed a distance *b* in front of the axis of the cylinder. It cuts from the surface of the cylinder two elements, the top views of which are both represented by the line *aa*. The front views of the same elements are found as in Article 89 *b*. That portion of the cylinder between these front views is the true section cut by the plane.

Find section cut by a plane parallel to H a distance *b above* the axis.

92. Cylinder.—*Axis Perpendicular to H; Cutting-plane Parallel to V* (Figs. 99, 100).

The plane cuts the circumference of the circle in the top view in two points, *a* and *a*. The space between the front views of the corresponding elements cut from the surface of the cylinder is the true section cut by the plane.

The plane was assumed a distance *b* in front of the axis. How would the section be found if the axis of the cylinder were perpendicular to V and the cutting-plane parallel to H, a distance *b* above the axis?

FIG. 97

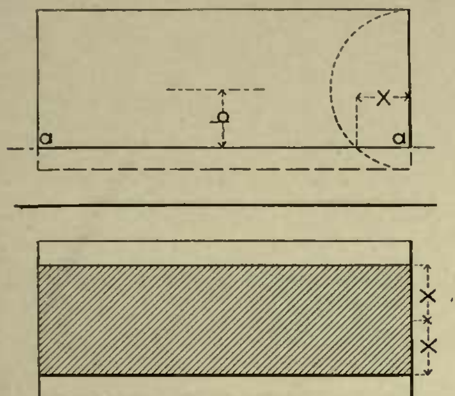


FIG. 98

93. SPHERE.—*Cut by a Plane Parallel to V* (Figs. 101, 102).

Assume the plane a distance *b* in front of the centre of the sphere. It cuts from the sphere a circle, the top view of which is a straight line, $\overline{aa}$. The front view of this circle is easily found (Art. 89 *e*), and the space within is the true section cut by plane.

FIG. 99

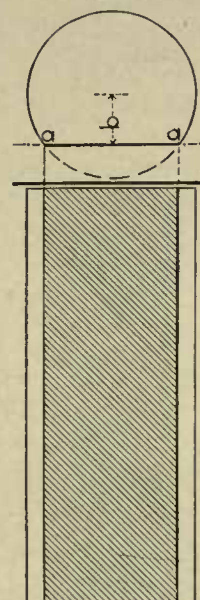


FIG. 100

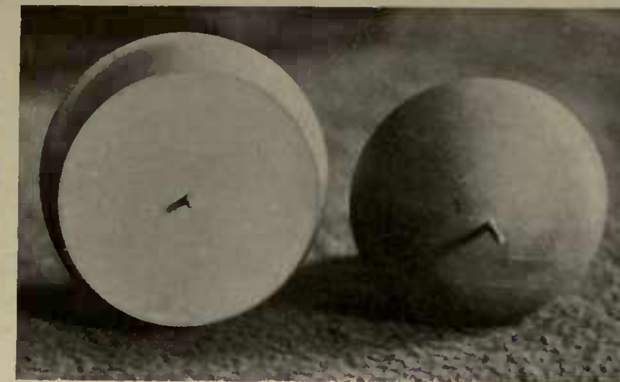


FIG. 101

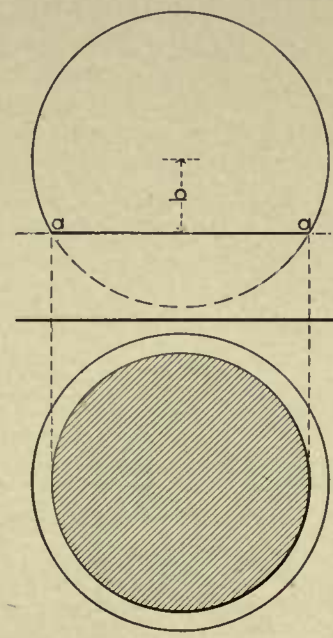


FIG. 102

Find section cut from the sphere by a plane parallel to H, a distance *b* above the centre of the sphere.

94. SPHERE.—*Cut by a Plane Perpendicular to H, at an Angle of X° with V* (Art. 86 *d*) *and a Distance* b *from the Centre of the Sphere* (Figs. 103, 104).

Whatever the curve cut from the surface of the sphere may be, its top view is the straight line *aa*. Let 1h be any point in *aa*. Then 1v is easily found, since 1 is on the surface of the sphere (Art. 89 *e*). By assuming several such

Fig. 103

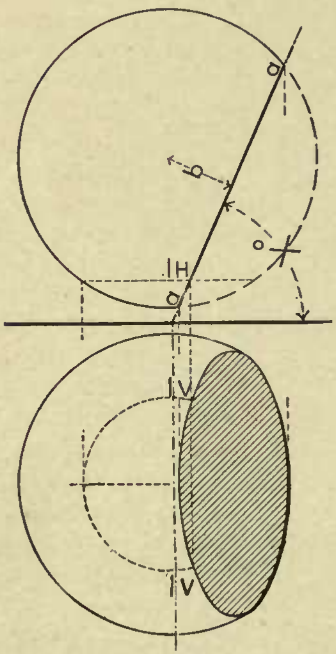


Fig. 104

points in $\overline{aa}$ and finding the corresponding front views, the front view of the section itself can be drawn. This front view is an ellipse, but the *true* section cut is a circle.

A shorter method is to find the four points in the front view, which are the ends of the major and minor axes, and construct the ellipse by one of the methods of Article 45.

95. Square Prism. — *Base Parallel to H; Cutting-plane Perpendicular to V, at Angle of X° to H* (Figs. 105, 106).

The plane is located by its traces (Art. 86 *d*). If the portion of the prism above the cutting-plane is removed, the top view (Fig. 106) shows the section cut, *but not in its true size or shape*, for the plane of the section is not parallel to H or V.

If the section is revolved until it is parallel to a plane of projection, it will be shown in its true outline. This is the usual way of showing such a section. In Figure 106 the section has been revolved until it is parallel to V. The view thus obtained is placed any convenient distance to one side of the front view of the prism.

96. Cylinder. — *Axis Perpendicular to V; Cutting-plane Perpendicular to H, at an Angle of X° with V* (Figs. 107, 108).

The method is similar to that of the preceding article. The section cut is an ellipse, the major axis of which is equal in length to *aa*, and the minor axis to the diameter of the circle. (Why?) If any other point on the ellipse, as 1′, is required, it is found as indicated in the figure.

Find section cut from a cylinder, the axis of which is vertical. Cutting-plane perpendicular to V, at an angle with H.

97. Cylinder. — *Axis Perpendicular to H, Cutting-plane Parallel to the Ground Line* (Figs. 109, 110).

Let the plane be given by its traces Xh and Xv (Art. 86 *b*). Revolve the cylinder on its axis one quarter way round, and let the cutting-plane be revolved with it; the latter now becomes perpendicular to V, and its traces in its revolved position are Xh(R) and Xv(R). The ellipse can now be drawn as in the preceding article, and the cylinder revolved back to its original position.

CONIC SECTIONS.

98. (*a*) Hyperbola.

In Figure 112 the axis of the cone is vertical.

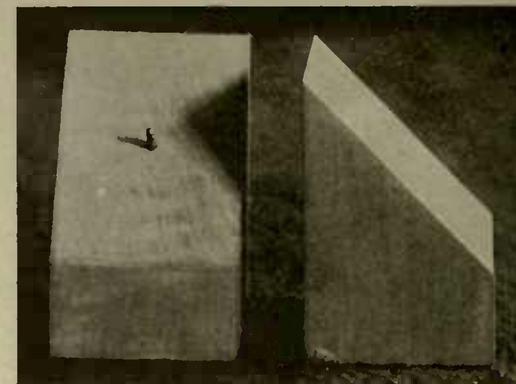


Fig. 105

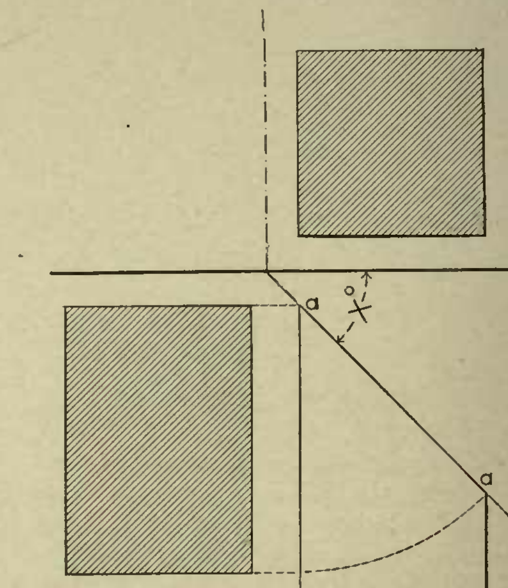


Fig. 106

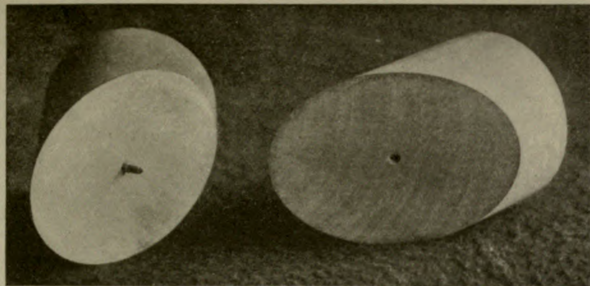


FIG. 107

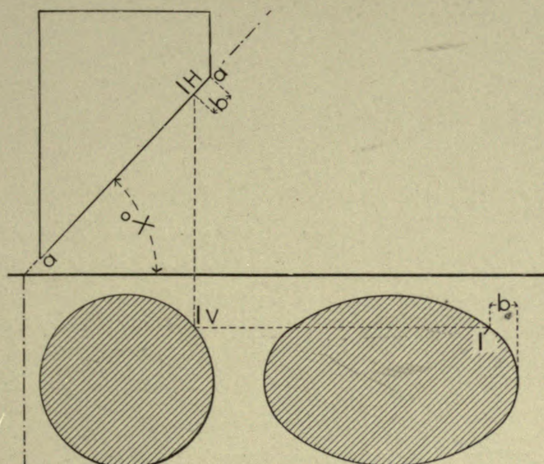


FIG. 108

The cutting-plane is parallel to V, a distance *b* in front of the axis. The horizontal trace of the plane is shown in the top view (Fig. 112). Whatever the curve cut from the *surface* of the cone may be, the top view of it is the straight line, *aa*. It remains to find the front view of the curve. Let the point 1, of which 1H is the top view, be any point in the curve. If 1 is in the curve, it must lie on the *surface* of the cone, and 1H being assumed, 1V can be found as in Article 89 *c* or 89 *d*. By assuming a number of points in the top view of the curve and finding the corresponding points in the front view, a series of points is obtained through which the curve can be drawn. This gives the *true* (Why?) outline of the section cut from the cone. It is a hyperbola.

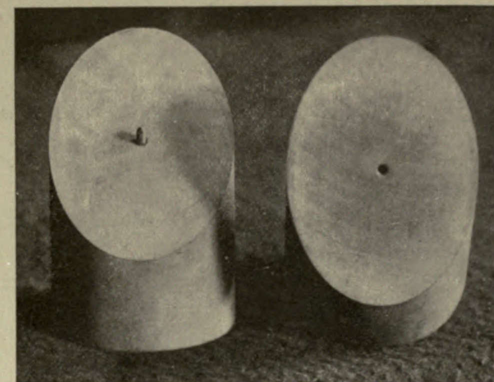


FIG. 109

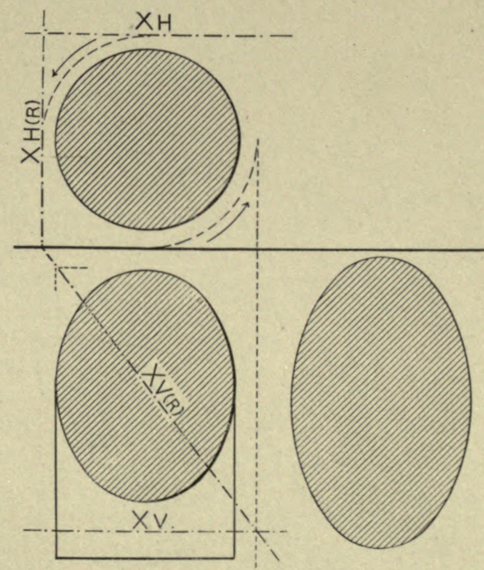


FIG. 110

Fig. 111

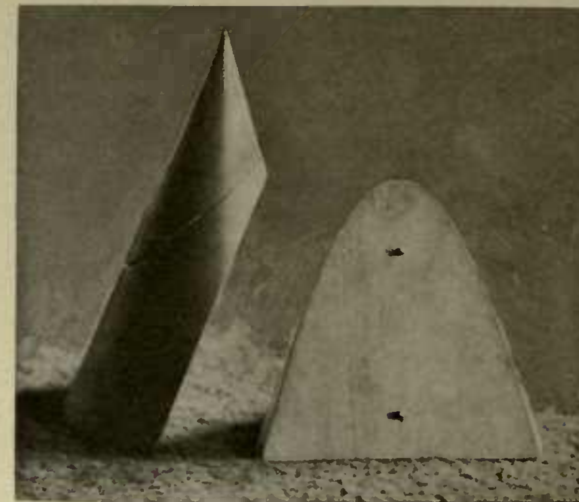


Fig. 113

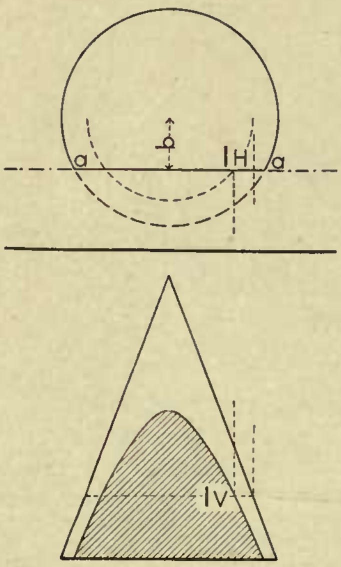


Fig. 112

The top view of the highest point of the curve will be directly in front of the centre of the circle. (Why?)

(*b*) Parabola.

In Figure 114 the cutting-plane is perpendicular to V and parallel to the extreme left-hand element of the cone. Whatever the curve cut from the surface of the cone may be, the front view of it is the straight line, *aa*. Let 1v be the front view of any point 1 in the curve. 1H can be found as in Article 89 *c* or 89 *d*. By assuming a number of points in the front view of the curve and finding the corresponding points in the top view, the top view of the curve itself can be drawn. This top view, however, is not the *true* outline of the section cut. This true section is shown to one side by a method similar to that of Articles 95, 96, and 97. The true outline is a parabola.

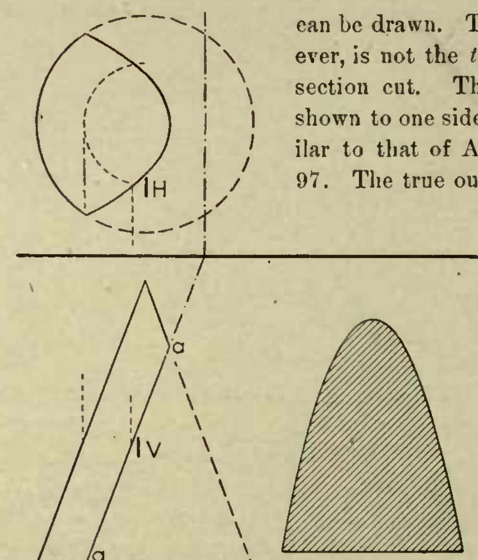
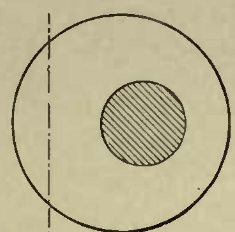


Fig. 114

FIG. 115



In the true section, what distance is equal to *aa?*

(*c*) ELLIPSE.

In figure 116 the cutting-plane is perpendicular to V, but the angle it makes with H is less than the angle between an element of the cone and the base. The front view of the curve is a straight line, *aa*. Assume points in this line, and find the top view of the curve as in the preceding article.

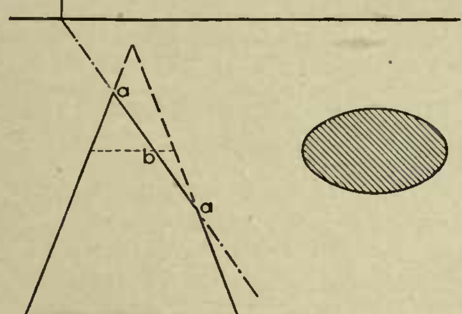


FIG. 116

The top view is not the true outline of the section; this is, accordingly, shown to one side. The true outline is an ellipse.

REMARK: The top view of the section in this particular illustration cannot be distinguished by the eye from a circle; it is in reality an ellipse.

PROBLEM: A much quicker method is to construct the ellipse on its two axes. How can the lengths of the minor and major axes be found?

CONIC SECTIONS.

Let X represent the angle an element of a right circular cone makes with the plane of the base. When this cone is cut by a plane, making an angle with the plane of the base:

Greater than X, the curve cut from the surface of the cone is a *hyperbola.*

Equal to X, the curve cut from the surface of the cone is a *parabola.*

Less than X, the curve cut from the surface of the cone is an *ellipse.*

99. SQUARE PRISM. — *Face at an Angle with V; Axis Perpendicular to H. Cutting-plane at an Angle with H, Perpendicular to V.*

The front view of the section cut is a straight line, *aa*. Revolve this section about an axis perpendicular to V, through the point *a*, until it is parallel to H (Fig. 117). The section will then appear in the top view in its true outline.

QUESTION: When the section is revolved, the front view of each limiting point will move in an arc of a circle as indicated in the figure until the front views of all these points are in a line, through *a*, parallel to the ground line. (Why?)

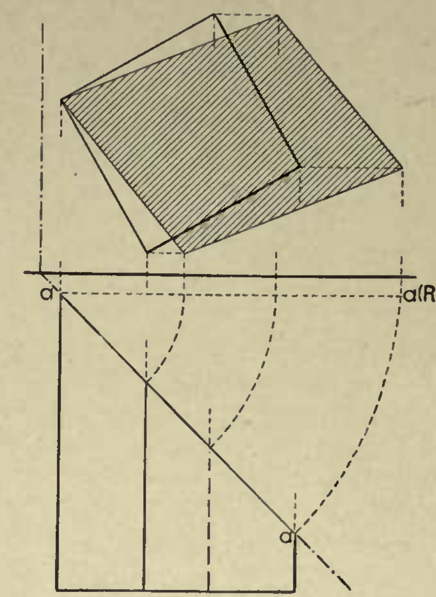


FIG. 117

Why do the top views of the corners of the prism all move in lines parallel to the ground line during revolution?

100. HEXAGONAL PYRAMID.

Let Figure 118 represent any hexagonal pyramid, the axis of which is vertical. The cutting-plane is parallel to V, a distance X in front of the axis. The top views of the points in which this plane crosses the edges of the

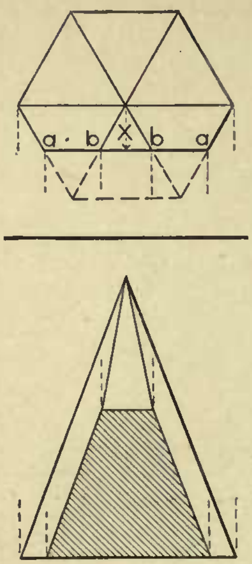


FIG. 118

pyramid are seen from inspection to be b and b. The plane cuts the perimeter of the base in a and a. The points av, bv, bv, and av are easily found and the true outline of the section cut determined.

QUESTION: Why should the lines between the points found in the front view be straight?

101. REMARK: A solid is sometimes cut by a plane at an angle with H and with V. Such a section involves more descriptive geometry than it is thought wise to introduce into an elementary work of this kind. To be able to draw the more difficult sections and intersections, one needs to study descriptive geometry itself.

INTERSECTION OF SURFACES.

102. When any two surfaces meet each other, they have a definite line of intersection —that is, a line common to both. Sometimes this line of intersection is a straight line, as, for example, when two plane surfaces meet, or it is a circle, as when two spherical surfaces intersect; but more often it is a *curve*, to determine which a geometrical construction is necessary. The most general problems of intersection are difficult of solution. In practice, however, nearly every object is bounded by plane faces or surfaces of revolution, the position of which with respect to H and V may be so assumed as to render the work of finding their intersection easy.

103. *General Method.*—A general method for finding points on the line of intersection of two surfaces is here given. It is assumed that at least one of the surfaces is a curved surface.

Pass a plane such that it will cut at least one line from each of the two surfaces. The point in which a line cut from one surface meets a line cut from the other surface is a point on the line of intersection. (For since it is in each of the lines, it is in each of the surfaces.) As many such auxiliary parallel planes should be passed through the two surfaces as may be necessary to give points close enough together to determine the curve of intersection.

Each auxiliary plane will usually give at least two required points—more often four. The plane should be so chosen that the line cut from either surface is one easily drawn, as, for example, a straight line or a circle. Thus, for a cylinder, pass planes parallel or perpendicular to the axis; for a cone, however, they should be *through* the axis or perpendicular to it.

104. INTERSECTION OF TWO CYLINDERS.

Let the axes of two cylinders of different diameters bisect each other at right angles. The axis of one cylinder is perpendicular to H, the axis of the other parallel to both H and V.

Conceive a plane passed through both cylinders parallel to V (Figs. 119 and 121). This plane will cut from the surface of the horizontal cylinder two elements, the front views of which are easily found (Art. 91). The front views of the two elements cut from the surface of the vertical cylinder are found as in Article 92.

The points in which the elements cut from the cylinders intersect are points in the curve of intersection. The points indicated by the small circles in Figure 121 are the front views of these points, and therefore lie in the front view of the curve of intersection.

By passing a number of these auxiliary planes parallel to V, a series of points may be obtained through which the front view of the curve of intersection may be drawn. This curve is shown in Figures 120 and 122.

QUESTIONS: What is the top view of the curve of intersection?

The plane passed through the two axes of the cylinders will give the extreme outside points of the curves. (Why?)

The plane passed tangent to the smaller cylinder will give the extreme inner points of the curves. (Why?)

Why would it be useless to pass a plane through the larger cylinder but too far in front to cut the smaller cylinder?

The invisible portion of the curve on the back of the cylinders is directly behind the visible portion. (Why?)

PROBLEMS: (1) Substitute for the vertical or the horizontal cylinder a cylinder with its axis parallel to V but at angle (say of 45°) with H.

(2) Assume the axes of the two cylinders parallel to H.

(3) Let the axis of the smaller cylinder be a short distance in front of or behind the axis of the larger cylinder.

For these three problems use the method explained above. In (2), however, the auxiliary planes are passed parallel to H, and in (3) pass planes back of the axis nearest V to find the invisible portion of the curve of intersection.

REMARK: Let a triangular prism, square prism, hexagonal prism, or other similar solid be substituted for the vertical or horizontal cylinder. Planes parallel to V cut straight lines from the cylinder and the solid, and the points of intersection are found as before.

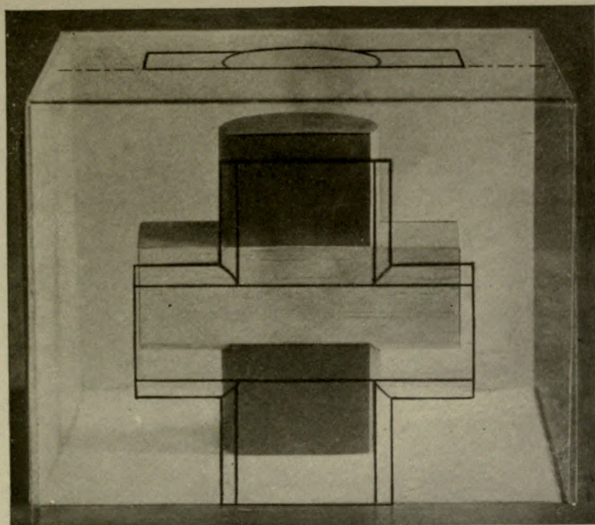


Fig. 119

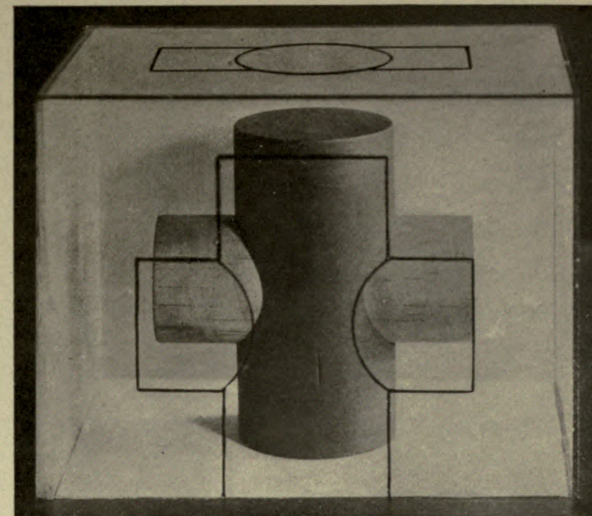


Fig. 120

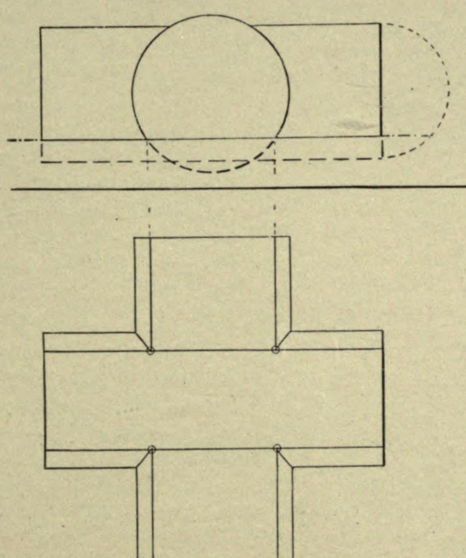


Fig. 121

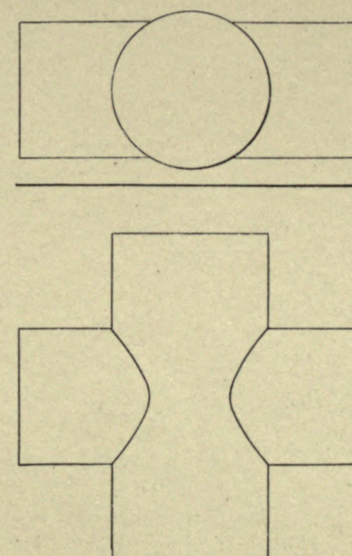


Fig. 122

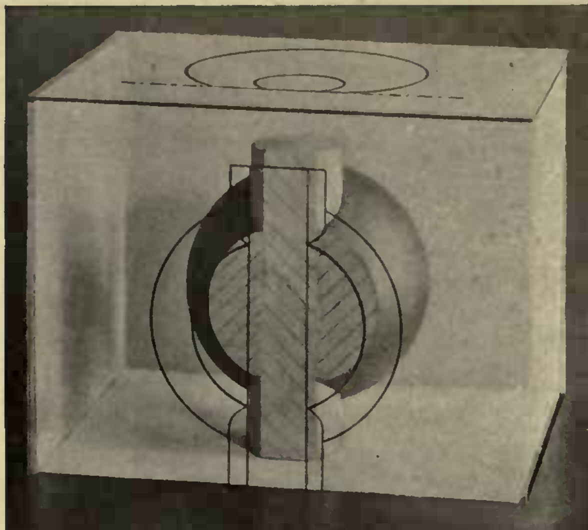


FIG. 123

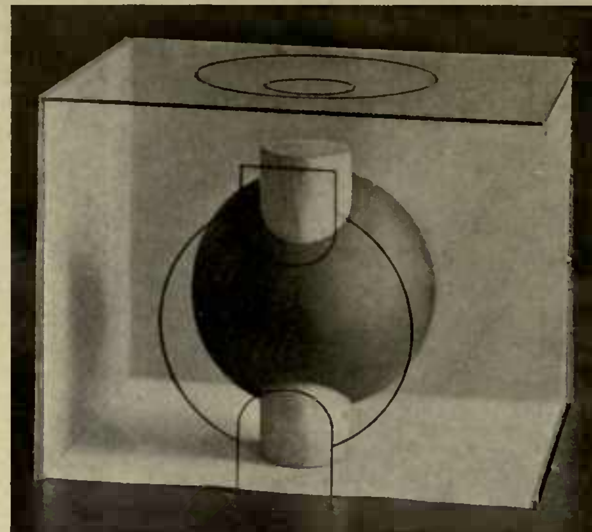


FIG. 124

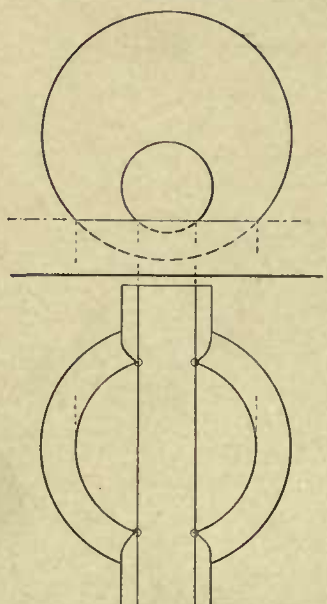


FIG. 125

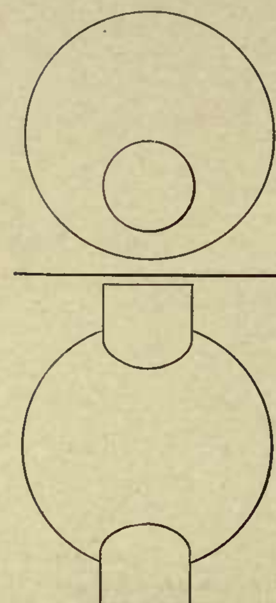


FIG. 126

105. INTERSECTION OF CYLINDER AND SPHERE.

In Figures 123 and 124 the axis of the cylinder is vertical, but does not go through the centre of the sphere. The auxiliary plane in this case is passed parallel to V. The two elements cut from the cylinder meet the circle cut from the sphere (Art. 93) in four points. These four points for each auxiliary plane are found in the front view, and the curve of intersection is thus determined.

In this intersection the invisible portion of the curve is not directly behind or below the visible portion. Auxiliary planes passed *back* of the axis of the cylinder or centre of the sphere will give points on the invisible portion. (Why?)

QUESTIONS: Assume the axis of the cylinder to pass through the centre of the sphere. What is the curve of intersection?

What auxiliary plane will give the lowest point of the upper curve of intersection and the highest point of the lower curve?

What auxiliary plane gives the extreme right and left points of the curve of intersection?

PROBLEM: Assume the cylinder with its axis to the right or left of the centre of the sphere, and a *small* portion of the cylinder not passing through the sphere at all. Use the same method.

106. Intersection of Cylinder and Cone.

Assume the axes of a cylinder and a cone to intersect at right angles, the axis of the cylinder parallel to H and V (Figs. 127 and 128). A horizontal auxiliary plane will cut straight lines from the cylinder and a circle from the cone (Fig. 129). The two elements cross the circumference of the circle in four points, the top and front views of which are shown in Figure 129. Thus a number of auxiliary cutting-planes parallel to H will determine the top and front views of the curve of intersection.

Note: In this problem the top views of the points of intersection are first found, and from them the front views are determined.

Questions: What auxiliary plane gives the highest point in the front view of the curve? Lowest?

What point of each curve is given by a plane through the axis of the cylinder?

Why not pass auxiliary planes parallel to V?

Why is the invisible portion of the curve directly behind the visible portion (front view)?

Problems: (1) Assume the axis of the cylinder in front of the axis of the cone.

(2) Assume the cylinder high enough up to cut the cone in two.

Use the method explained above for both problems.

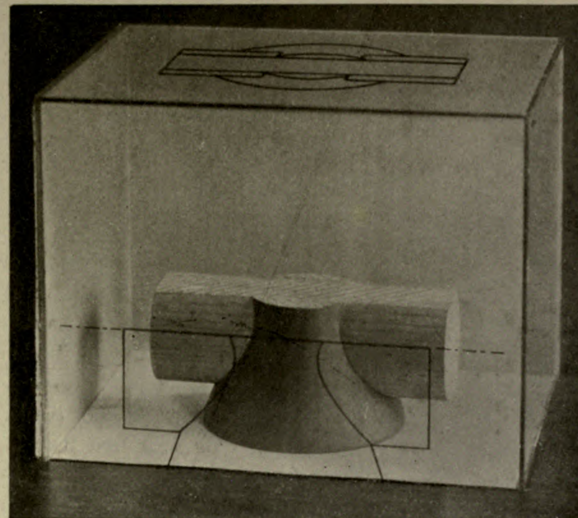


Fig. 127

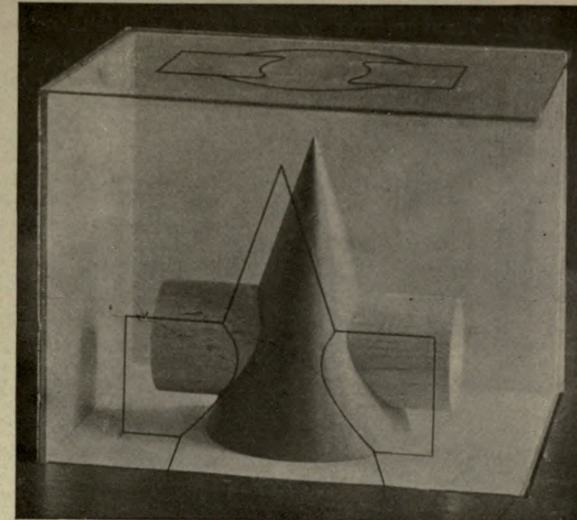


Fig. 128

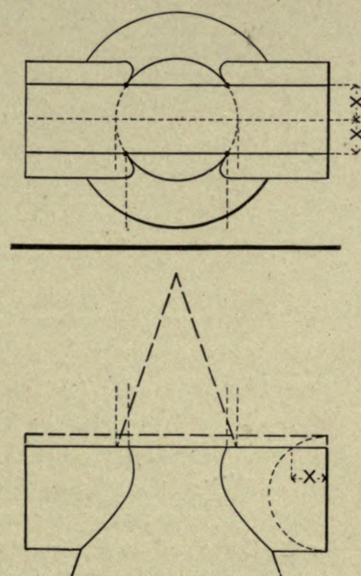


Fig. 129

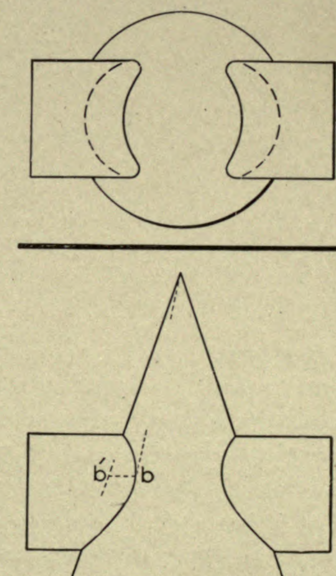


Fig. 130

107. Intersection of Cylinder and Hexagonal Prism.

Let the axes bisect each other at right angles; axis of the cylinder vertical. The method is the same as for two cylinders (Art. 104). The work is indicated in Figure 131.

108. Intersection of Hexagonal Prism and Sphere.

Use the method of Article 105. The work is indicated in Figure 132.

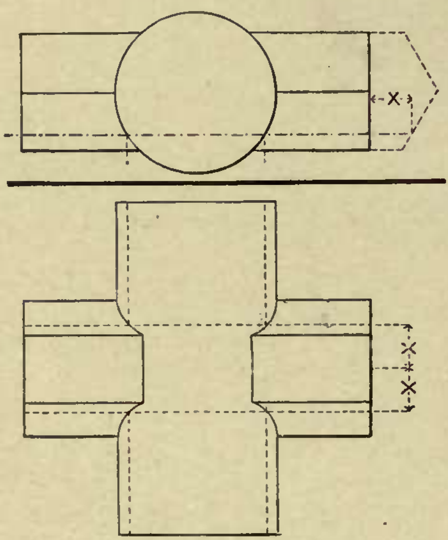


Fig. 131

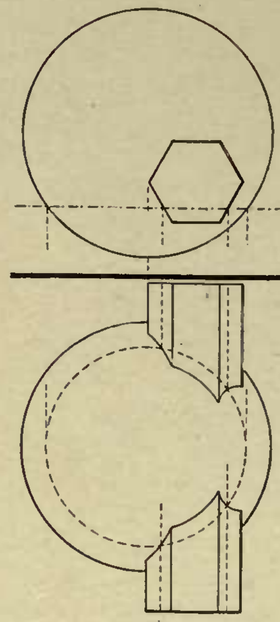


Fig. 132

109. Development of Surfaces.—When a surface is unfolded or unrolled into a plane, the outline is called its development. Only cylinders, cones, and plane surfaces can be thus developed.

The surface may be opened or cut at any desired point to begin the development.

110. (*a*) *Development of the Smaller Cylinder of Figure 122.* — In Figure 122 let it be required to develop one end of the smaller cylinder, and for sake of clearness in explanation let this end be taken by itself (Fig. 133). When unrolled, the circumference of the base will become a

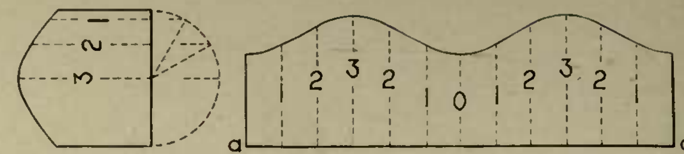


Fig. 133

straight line, *aa*, the length of which is computed from the diameter of the cylinder. The distance from the base to the curve of intersection can be measured at regular intervals and transferred to the development as follows: (1) Draw any number of elements equal distances apart on the surface of the cylinder. This is done by revolving the circumference to the position indicated by the broken circle, dividing it and revolving it back again. Draw the elements 1, 2, and 3. These elements are equal distances apart on the surface of the cylinder, although the lines themselves are not equal distances apart in the drawing. (Why?) (2) Divide the line *aa* in the development into as many equal parts as were laid off on the circumference. From each of the points thus obtained lay off the lengths of the corresponding elements, 1, 2, 3, etc. Through the ends of the elements draw the curve. The surface thus obtained, if rolled together, would form a small cylinder which would fit against the larger cylinder of Figures 120 and 122.

Since the curve of intersection is symmetrical, a number of the elements are of the same length; these have the same numbers in the figure. Thus there are four elements of the same length marked 2. The development is usually found directly from the original view of the intersection.

(*b*) *Development of the Cylinder of Figure 126.*—In Figure 126 an end of the cylinder can be developed by the method already given. Each element must be measured by itself, however, and the distances to the invisible as well as to the visible portions of the curve must be used.

Note: The invisible portion of the curve is not shown in Figure 126.

(*c*) *Development of the Cone of Figure 130.*—In Figure 130 the development of the cylinder can be found by the usual method. In the development of the cone (Fig. 134) the radius of the circular arc *aa* is equal in length to an element of the cone (Why?), and the length of the arc itself is equal to the length of the circumference of the base. This arc is divided into as many equal parts as were laid off on the circumference of the base

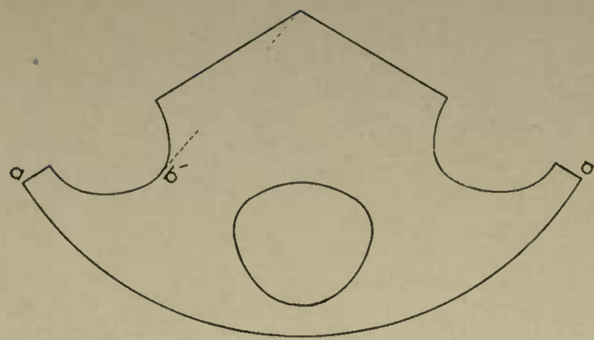


FIG. 134

of the cone, and the corresponding elements drawn from the vertex. The *true* distances along any one of these elements to points on the curve can be found by revolving the element until it is parallel to H or V (Art. 73), and these distances laid off on the corresponding element in the development. For example, revolve the element through the point *b* (Fig. 130) until it is parallel to V. The point *b* will move to *b'*, and the distance from the vertex to *b'* will be the distance to lay off along the corresponding element in the development (Fig. 134).

111. The developments of the surfaces of Articles 90 to 100 are easily found by the methods of Articles 110 (*a*), (*b*), and (*c*).

In finding the intersection of the surfaces of two solids, it makes but little difference whether the axes of the solids intersect or not. If, however, the axes are not at right angles to each other, the problem is usually more difficult. (See Art. 101.)

SHADOWS

112. It is sometimes required to find the shadow cast by an object on a horizontal or vertical plane. In this case it is best to use the *first* angle of projection, letting H and V represent the planes upon which the shadow falls. If the object is in the third angle there can be no shadow on H, unless light comes from *below* the object instead of from *above* it.

REMARK: The subject of shadows is of little practical value. It, however, affords practice in the use of the first angle of projection and furnishes examples in tinting; otherwise its importance would hardly warrant the space required for explanation of principles.

113. Problems in shadows fall into three classes:

First.—The shadow cast by an object on the planes of projection.

Second.—The shadow cast by it upon some neighboring object.

Third.—The line of separation of light and shade on the object itself.

114. SHADOWS ON H AND V.—*General Method.*—(1) Select from inspection of its views those limiting points of an object which cast shadows.

A point of an object casts a shadow when the ray of light which strikes it, if produced, meets H or V *without passing through any part of the object.*

(2) Find where the ray of light through each of these points pierces H or V.

The direction of the rays of light is assumed to be such that each of the two views of any particular ray makes an angle of 45° with the ground line.

(3) Draw the outline of the shadow through the views of the points found in 2.

115. TO FIND WHERE ANY LINE PIERCES H OR V.—To find where the line 1–2 (Fig. 135) pierces H, produce its front view, 1v 2v, until it meets the ground line in Xv. The two points, Xv and Xн, are the two views of the point in which the line 1–2 pierces H. (Why?) If the line meets V instead of H, the views of the point are found as indicated in the figure for the line 3–4.

Every ray of light, if produced, must meet both planes of projection, since the latter are of indefinite extent. Thus, in Figure 135, the ray 1–2 meets the horizontal plane at Xн and the vertical plane at Yv.

Shadows are never drawn behind or below the ground line, but it is sometimes necessary to find out where a ray would go if produced.

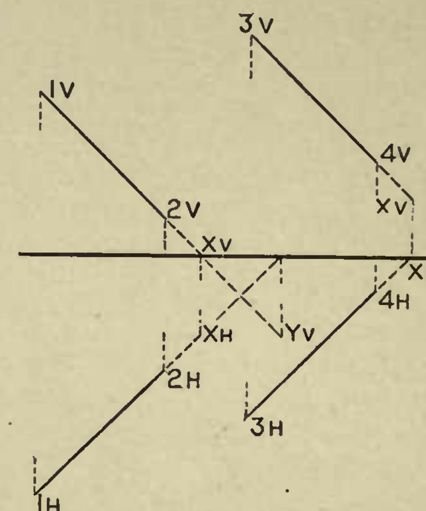


FIG. 135

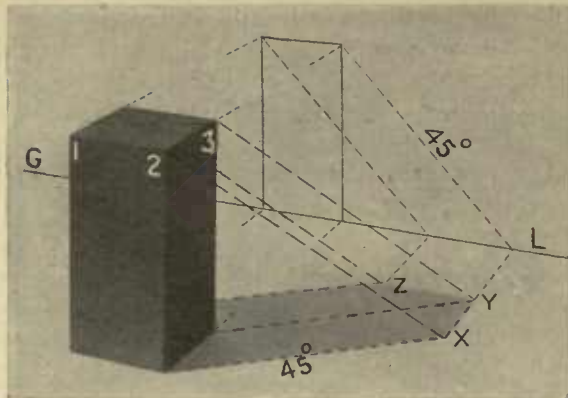


FIG. 136

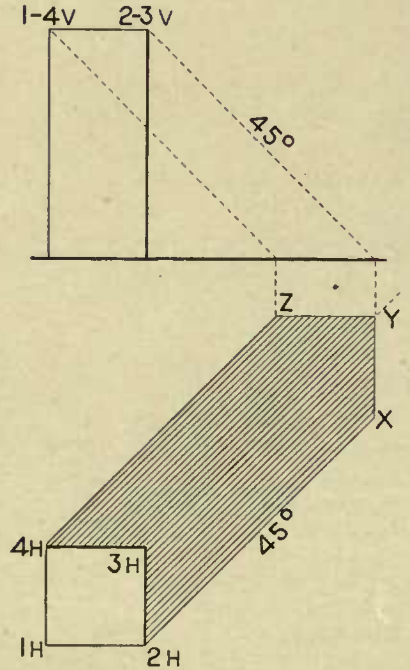


FIG. 137

116. SHADOW OF A SQUARE PRISM ON H.

If the base of the prism (Fig. 136) is in H, the points 2, 3, and 4 cast shadows. A ray of light through 1, for example, must pass through the prism to reach H; therefore 1 does not cast a shadow. The points in which the rays of light through 2, 3, and 4 pierce H are respectively X, Y, and Z. The views of these points are found, and the outline of the shadow drawn as indicated in Figure 137.

117. It is evident from the above example that:

(1) *If an edge of an object is parallel to a plane, its shadow on that plane is a line parallel to itself and of the same length. If any plane surface is parallel to a plane, the shadow on that plane is identical in outline with the surface itself.*

(2) *Vertical edges in an object cast 45° lines in the shadow.*

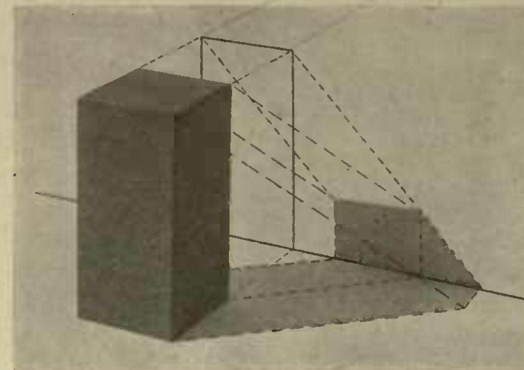


FIG 138

When a surface is parallel to a plane it is usually necessary simply to find the shadow cast by one of its limiting points to determine the whole shadow.

118. SHADOW ON H AND V.

If an object is too near V, part of the shadow will fall on V. Figures 138 and 139

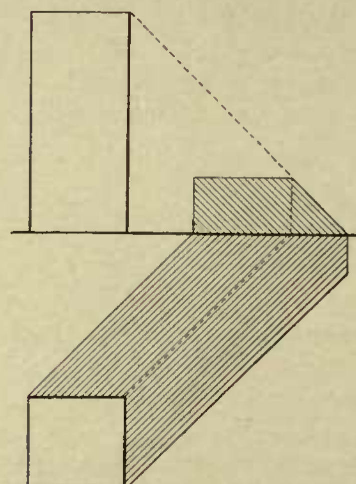


FIG. 139

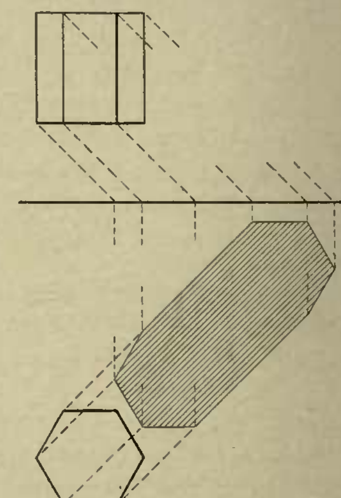


FIG. 140

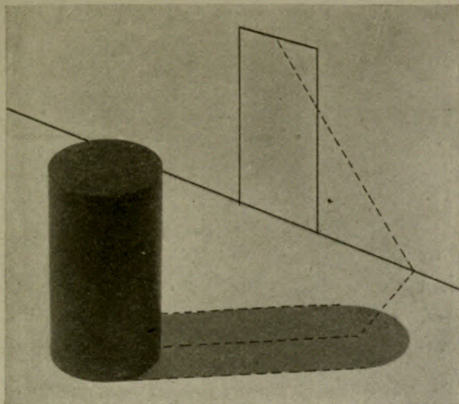


FIG. 141

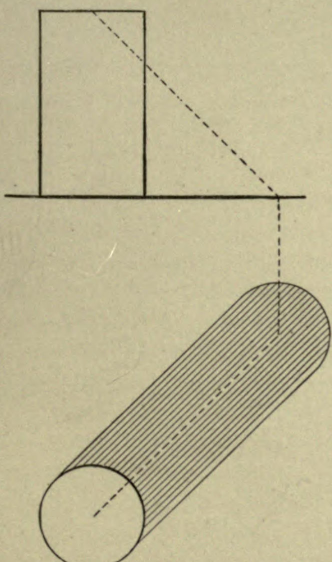


FIG. 142

illustrate such a case, the prism of Figure 136 having been moved nearer to V. In this example, it is necessary to find where certain rays of light pierce V instead of H (Art. 115). The method is indicated for the ray of light through one corner by dotted lines (Fig. 139).

119. SHADOW OF A HEXAGONAL PRISM ON H.

The method used is exactly like that of Article 116. The work is indicated in Figure 140.

120. SHADOW OF A CYLINDER ON H.

Figures 141 and 142 illustrate the shadow of a cylinder with its axis vertical. Since the upper base is parallel to H, its shadow is a circle. Hence find the point in the shadow where a ray of light through the centre of the upper base would strike H. The whole outline is then easily found.

121. SHADOW OF TWO BLOCKS ON H.

Figures 143 and 144 illustrate the shadow of two blocks on H. Note that points in the *lower* base of the upper block cast shadows.

122. SHADOW OF CIRCLE PARALLEL TO V.

Figure 145 shows the top and front views of a circle parallel to V. Its shadow on H is an ellipse, points of which are easily found as illustrated by 1s.

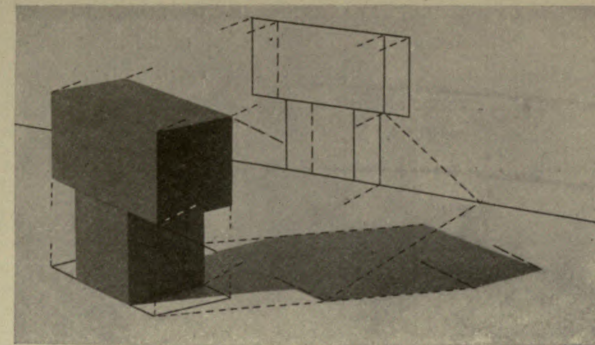


FIG. 143

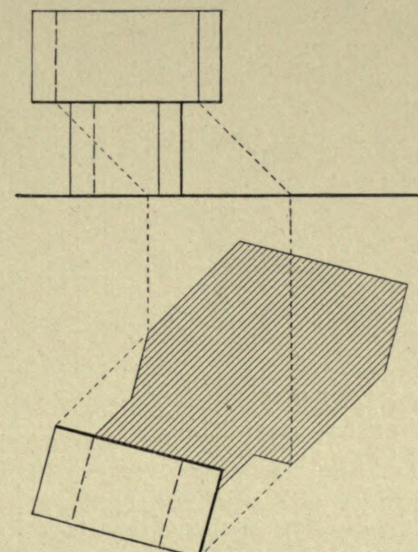


FIG. 144

123. Shadow of Circle Perpendicular to H and V.

Figure 146 is another common case where the circle lies in a profile plane. The shadow construction is different from the preceding problem, because one view of a point on the circumference cannot be determined by dropping a perpendicular from the other view. Let any point, as 1v, be given; 1h can be found as indicated. Draw rays through these points and proceed as before.

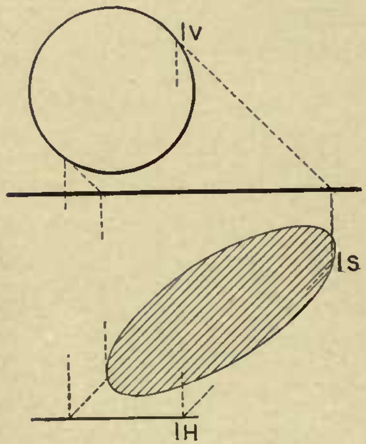


Fig. 145

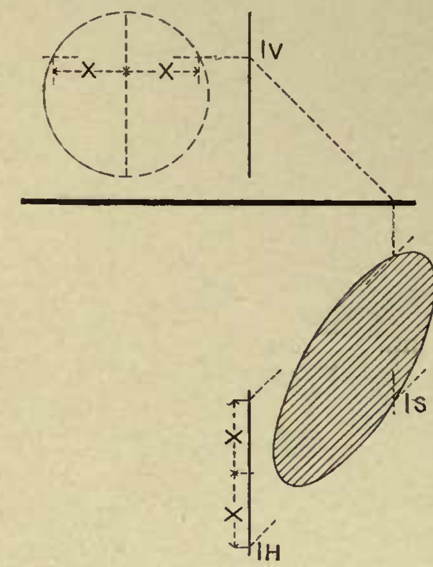


Fig. 146

124. Shadow of One Object upon Another.—The foregoing paragraphs relate to shadows on the co-ordinate planes only. A much more difficult problem is to find the shadow cast upon some second body whose shape is known. The general method is to draw the views of the rays through limiting points of the object which cast shadows, and find where these rays meet the surface which receives the shadows. The difficulty lies in finding out *where* the rays meet the surface in question. A different method has to be employed in each case, depending upon the surface on which the shadow falls.

125. Shadow of a Part of an Object on Another Part.

Figure 147 is an example where the shadow upon the object itself has to be determined as well as the shadow on the horizontal plane.

The object is a square prism with a square projecting rim, and its shadow on the horizontal plane is found by the method already explained.

The method of finding the shadow of the rim on the lower part of the prism is indicated for one point by the dotted lines. Thus in the top view, for example, the dotted line through the front corner represents the top view of a ray of light through the *under* corner of the rim. This line is drawn until it strikes the front face of the prism. The point on the front face thus found is a point in the shadow and is projected up to the front view.

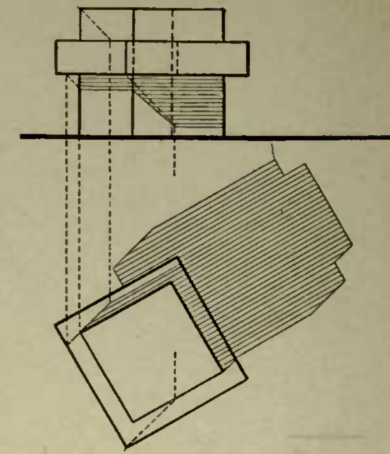


Fig. 147

The dotted line through the upper left-hand corner (front view) is drawn until it strikes the rim, and the *top* view of the point thus found is a point of the shadow cast by the prism on the rim.

126. Shadow of a Cone upon a Cylinder.

In Figure 149 the direction of the light was assumed in such a way as to make the shadow correspond to that in the photograph (Fig. 148). The dotted lines through the vertex of the cone (front view) and the shadow of the vertex (top view) indicate the directions of the front and top views respectively of a ray of light.

The shadows of the cylinder and cone on the horizontal plane can be found separately by methods already described (using, however, the new directions for the views of a ray of light). Shadows of the cylinder ends are found as in Article 122.

To find the shadow of the cone on the cylinder, first find the two elements of the cone which determine the shadow. To do this, imagine a horizontal plane through the base of the cone and find the point where a ray of light through the vertex would pierce this plane. (The *front* view of this point is at *b*.) From the top view of this point (not shown in the figure) draw tangents to the top view of the base of the cone, and from the points of tangency draw

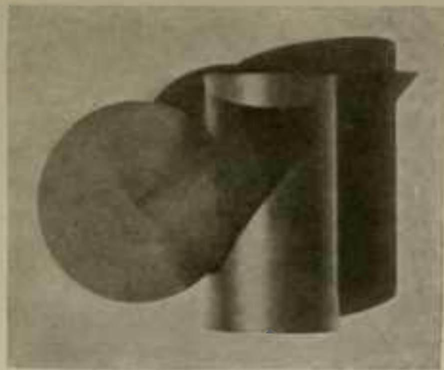


FIG. 148

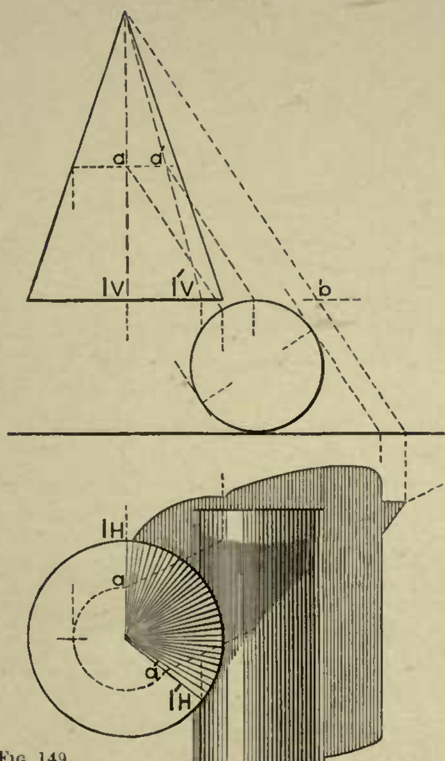


FIG. 149

lines to the top view of the vertex. These two lines will be the top views of the required elements. The front views of these elements are easily found; they are lines from the vertex to 1v and 1′v.

On the front view of one of these elements assume a point as a, and find a in the top view. Through a in the front view draw the front view of a ray of light until it strikes the circle (front view of the cylinder). The point of contact is the front view of the point in which this particular ray of light strikes the surface of the cylinder. The corresponding top view is easily found, and is in the edge of the shadow. By assuming a number of such points and repeating the process, the outline of the shadow can be determined.

REMARKS: The dotted circle (top view) is used simply to find the top views of a and a', points assumed for illustration in the front view.

The element from the vertex to 1v in the front view appears like a vertical line. It is not quite vertical. If the rays of light had been assumed in the usual way, this element would have been in the left-hand portion of the cone.

The curved edges of the shadow are portions of two ellipses. The ellipses correspond to those which would be cut from the surface of the cylinder by two planes. Through what lines would these planes be passed?

If a line is drawn from the centre of the circle (front view of the cylinder) perpendicular to the front view of a ray of light, it will cut the circumference in a point which is a front view of an element. The top view of this element terminates the shadow of the cone on the cylinder.

A portion of the base of the cone casts a shadow on the cylinder. If this were not so, the curve forming the edge of the shadow would not reverse. This portion of the shadow is found by assuming points in the circumference of the base (instead of in either of the two elements) and proceeding as before.

127. The line of separation of light and shade on an object can usually be determined by inspection after the shadows on the co-ordinate planes have been found. In many cases it can be determined by preliminary inspection without drawing a line. When the body has projecting edges which cast shadows on itself, the problem is like that of Article 126, and may become quite difficult.

128. SHADE LINES. (See Art. 36.)—The shadows described in the preceding paragraphs are rarely constructed except on important drawings which are finished up with a brush. Ordinarily, no brush-shading is used, and the appearance of the drawing is much improved by the use of shade lines (Art. 36).

It is almost universal, in working drawings, to shade the right-hand and lower edges *in all views*. This is equivalent to changing the direction of the ray of light in top views and end views.

Adhering to the common method, these general rules may be given:

(1) Shade right-hand and lower edges in all views.
(2) Shade left-hand and upper edges of all holes.
(3) Lines between visible planes are *not* shaded.

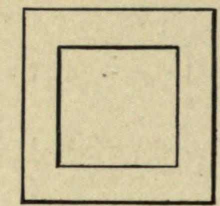


FIG. 150

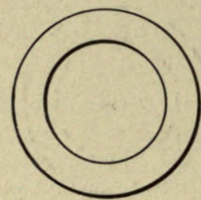


FIG. 151

The lower right-hand quadrant of *outer* circles and the upper left-hand quadrants of inner circles are shaded (Art. 36 *b*).

NOTE: In some of the line drawings illustrating shadows the above method was not used. The draftsman needs to use judgment and common-sense in applying general rules, remembering that a shade line should lie between a light and a dark surface.

129. It should be noted that curved surfaces, like cylinders and cones, have no abrupt line of demarcation between light and shade. The lightest portion of such surfaces is that normal to the rays of light, and the darkest is tangent to the rays; the depth of shade depends on the amount of light reflected from each part. The shading should be lightened somewhat at the very outside edge of curved surfaces to give the appearance of light reflected from adjoining objects.

CHAPTER VII

PERSPECTIVE

By E. H. LOCKWOOD, M.E.

130. Introductory.—Except in architecture, but little application of perspective is made in Mechanical Drawing. The conventional isometric and cabinet projections which are used as a substitute are easier to execute from measurement, but they do not always give a satisfactory appearance. The principles of perspective, however, are not difficult to acquire, and they can be applied in a mechanical way without special artistic training; nevertheless, distorted results may follow, even from a correct application of the laws of perspective, if they are applied to absurd or limiting positions. For example, to represent on paper the appearance of a six-inch cube at a distance of *three* inches from the eye is an absurdity, yet it can be drawn by the rules of perspective as easily as in any other position. It should be remembered that a perspective drawing represents the object as it actually appears to the eye; hence the best point of view should be obtained, and good judgment in this matter is as important as a formal knowledge of the rules of perspective.

131. Perspective Drawing Defined.—As treated in mechanical drawing, the problem of perspective is: Given the top and front views in orthographic projection (Chap. V.), to construct the *perspective projection*.

The subject is sometimes called *linear perspective*, since it relates only to the lines of the drawing. Perspective is evidently more laborious than orthographic projection, because the top and front views, instead of being the end sought, are only preliminary to it. But the top and front views need not be drawn complete in all cases. Sometimes they may be drawn only in part, or omitted altogether.

The relation of perspective to orthographic projection must be kept clearly in mind from the start. In Figure 152 the object is in

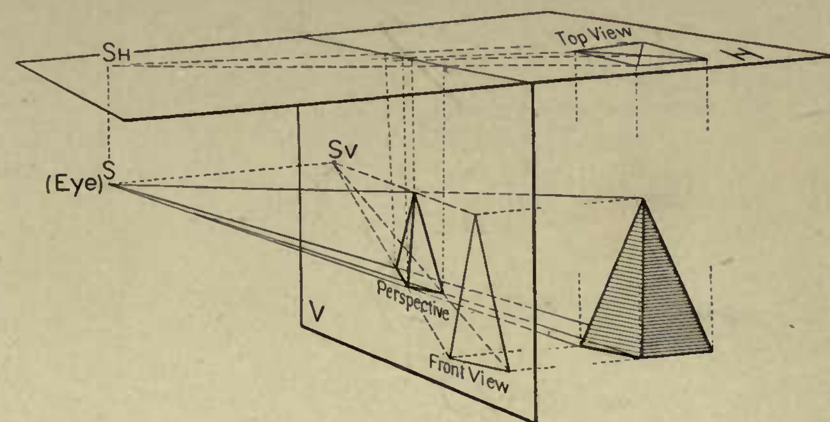


Fig. 152

the third angle, the top and front views being drawn in the usual way. The eye is in the *fourth angle*, in order to see the object through the vertical plane, which is assumed transparent. The perspective drawing is made on the vertical plane, the outline being determined by straight lines drawn from the object to the eye. The intersection of these lines (or *rays*) with the vertical plane gives a drawing which, if shaded and colored, would exactly represent the object as seen from the assumed point.

In most treatises on Perspective the object and the eye of the observer are taken in the first angle. Then it is not convenient to make the perspective drawing on V. Another plane is assumed parallel to V, and placed between the object and the eye, and is called the *Picture Plane*.

The term Picture Plane will be employed in this chapter, though it is coincident in every case with V.

132. Picture Plane.—The plane on which the perspective drawing is made is called the Picture Plane.

The plane of the paper, therefore, corresponds to the picture plane. In this chapter the picture plane coincides with V, the vertical plane of projection, in every case.

133. Point of Sight.—The position of the eye is called the Point of Sight (Fig. 152). It is denoted by the letter S (projections Sv, Sh). Where no ambiguity would result, the vertical projection of the point of sight is also denoted by S.

The perspective drawing varies with every position of the eye, even if the object is fixed, as is evident from Figure 152. Hence the importance of choosing the best position for the point of sight. This is immaterial for the present, however, since the methods are the same wherever the point of sight is chosen.

134. Elementary Construction.—The simplest construction of a perspective drawing is based upon the use of two projections of the point of sight. The method is illustrated in Figure 153. Sv and Sh are the two projections of the point of sight in the fourth angle (Art. 131). In the fourth angle a point is below and in front of the ground line. Hence its two views are on the same side of the ground line. The pyramid 1 2 3 4 5 is given in the usual way by the top and front views.

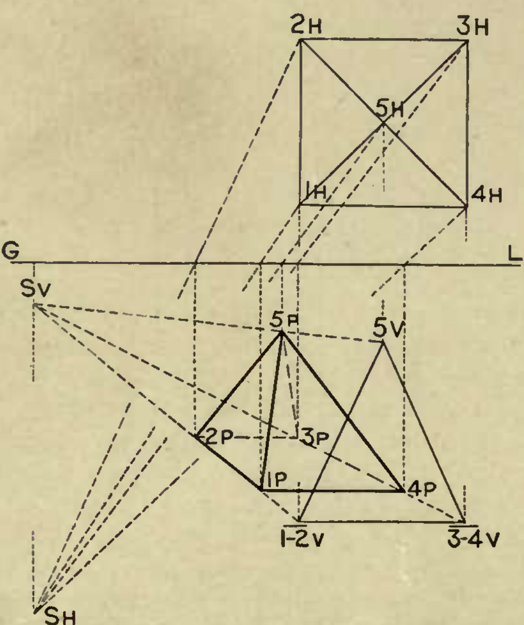


Fig. 153

(*a*) Join 1h, 2h, etc., to Sh. These lines are the horizontal projections of rays to the point of sight, and need be drawn only to GL.

(*b*) Join $\overline{1-2}$v, $\overline{3-4}$v, 5v to Sv. These lines are the vertical projections of rays to the point of sight.

(*c*) From the intersection of each line of the first group (*a*) with GL, drop perpendiculars to the corresponding line of the second group (*b*). The outline 1p 2p 3p, etc., thus determined, is the perspective of the pyramid.

It will be seen that making a perspective drawing by this method is a simple process. Its defect is the use of Sh, which generally falls beyond the limits of the drawing-board. Hence, in actual work, a modification of this method, not involving Sh, is used. This construction is of fundamental importance, however, and should be understood before using the abridged method.

135. Lines in Special Positions.—The perspective of any line can always be determined by the method of Article 134. Yet in some cases the perspective can be found much more simply, at least as far as its *direction* is concerned. There are three important cases:

(*a*) *When a line is perpendicular to the picture plane, its perspective converges towards* Sv. See Figure 153 for an example, where the line $\overline{1\text{h}-2\text{h}}$ is perpendicular to the picture plane (V) and its perspective 1p–2p points towards Sv.

(*b*) *When a line is parallel to the picture plane, its perspective is parallel to the front view of the line.* See Figure 153, where the line $\overline{1\text{h}-4\text{h}}$ is parallel to the picture plane and the perspective $\overline{1\text{p}-4\text{p}}$ is parallel to $\overline{1-2}$v $\overline{3-4}$v.

(*c*) *Horizontal lines at 45° to the picture plane converge in perspective towards points on either side of* Sv, *and at a distance from* Sv *equal to that of the point of sight from the picture plane.*

The truth of the above statement can be demonstrated from Figure 154. $\overline{1\text{v}-2\text{v}}$ and $\overline{1\text{h}-2\text{h}}$ are the front and top views of a horizontal 45° line, one end of which is in the picture plane. The perspective of the line is $\overline{1\text{v}-2\text{p}}$, found by the method of Article 134. Now, instead of terminating the line at 2, let 2 recede indefinitely to the right along the line. The dotted line joining Sv to 2v will become a horizontal line through Sv. The

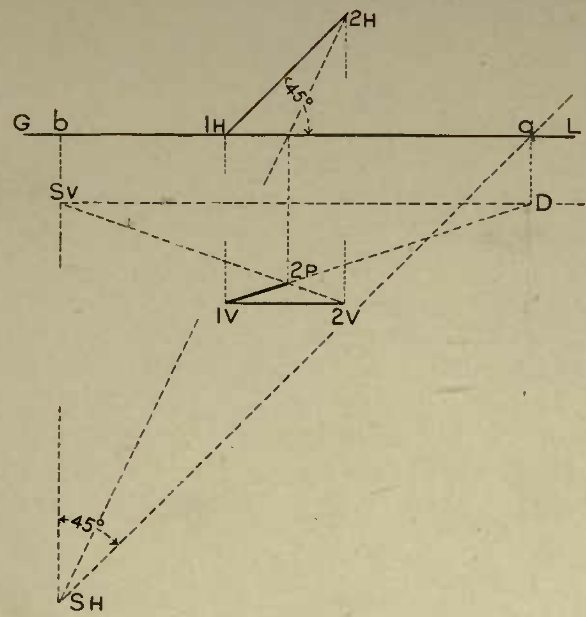


Fig. 154

line joining SH to 2H will become a 45° line through SH crossing GL at *a*. Dropping a perpendicular from *a*, the perspective of the point (when infinitely distant) is found at D. Hence the perspective of the line $\overline{1\text{–}2}$ extends only from 1v to D, however long the line itself may be. But $\overline{\text{SH–b}}$ (= $\overline{\text{Sv–D}}$) is the distance from the point of sight to the picture plane (Fig. 152); hence the statement is proved.

Since the location of D depends only on the direction of $\overline{1\text{–}2}$, and not on its position, it follows that any line parallel to 1–2 would also converge towards D.

Horizontal 45° lines sloping in the opposite direction would converge towards a point situated at an equal distance to the left of Sv.

136. Horizon.—A horizontal line through the vertical projection of the point of sight is called the horizon. It is used for construction purposes only, and contains the important points D on either side of Sv (Art. 135 *c*).

137. Points of Distance.—Points in the horizon at a distance from Sv equal to that from the point of sight to the picture plane are called the Points of Distance, or Measuring Points. They are denoted by the letter D.

The distance from the eye (point of sight) to the paper (picture plane) is the first thing to be assumed in making a perspective drawing. Hence the location of the points D, D, is always known. Horizontal 45° lines always extend, in perspective, towards one of these points (Art. 135 *c*). This gives a method of measuring distances along lines perpendicular to the picture plane (Art. 135 *a*); hence the term *measuring points*.

138. Vanishing Points.—In perspective, parallel lines converge towards a point called the Vanishing Point. Every set of parallel lines has its own vanishing point, depending on the direction of the lines. All horizontal lines vanish somewhere in the horizon. If perpendicular to the picture plane they vanish at Sv (Art. 135 *a*). If horizontal 45° lines they vanish at D (Art. 135 *c*).

139. Construction of the Drawing.—By using the measuring points (Art. 137) the horizontal projection of the point of sight may be omitted. This overcomes the defect of the method described in Article 134. The vertical projection of the point of sight will hereafter be denoted by S.

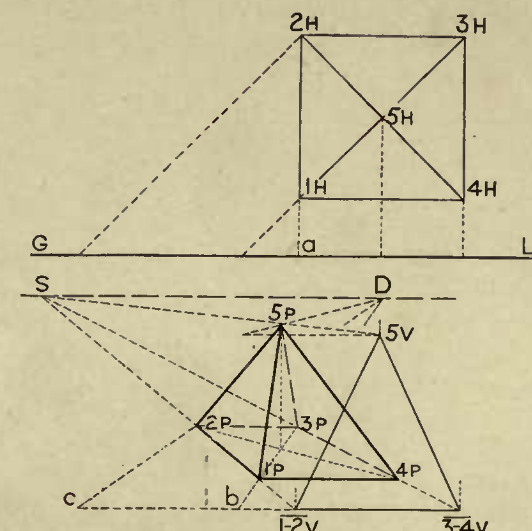


Fig. 155

In Figure 155 the projections of the pyramid 1H, 1V, 2H, 2V, etc., are taken exactly as in Figure 153, Article 134, in order that the two methods may be compared. The following are the steps of the process:

(*a*) Assume S at any desired point and draw the horizon through it.

(*b*) Take D at any arbitrary distance on either side of S.

Hints regarding the choice of these two points will be given later (Art. 144).

(*c*) Connect each corner of the vertical projection to S by dotted lines (Art. 135 *a*).

(*d*) Draw a horizontal line through $\overline{1\text{–}2\text{V}}$, and lay off on it to the left distances equal to $\overline{a\text{–}1\text{H}}$, $\overline{a\text{–}2\text{H}}$ from the top view, giving *b* and *c*.

(*e*) Join *b* and *c* to D, and get the desired perspective of the two points at 1P and 2P.

(*f*) The pyramid can be completed from these points, because $\overline{1\text{P–}4\text{P}}$ is parallel to $(\overline{1\text{–}2\text{V}})\text{–}(\overline{3\text{–}4\text{V}})$ (Art. 135 *b*), and likewise $\overline{2\text{P–}3\text{P}}$. Draw diagonals of the base and erect a perpendicular to get the vertex, or find it by measurement as shown by the dotted lines.

The truth of the method employed to find 1P and 2P rests upon the fact that the lines joining *b* and *c* to D are 45° lines (Art. 135 *c*). Hence right triangles are formed with the right angle at $\overline{1\text{V–}2\text{V}}$. The opposite sides are equal, as $(\overline{1\text{–}2\text{V}})\text{–}b = \overline{1\text{H–}a}$. Therefore the correct measurement is made from $\overline{1\text{V–}2\text{V}}$ towards S.

PERSPECTIVE.

140. Reduced Points of Distance.—The eye is generally assumed at such a distance from the paper that D falls beyond the limits of the drawing-board. This difficulty is easily avoided by using *reduced points of distance* — that is, new points at one-half, one-quarter, or some other simple fraction of the distance from S to D. The construction is shown in Figure 156. D is inaccessible, and it is desired to measure 2″ from 1V towards the point of sight. Take $D/_2$ half-way out to D, lay off 1″ to the left of 1V, and join. The point 1P thus obtained is the same as if the full size dimensions were used. If $D/_4$ had been used, one quarter of 2″, i. e., $\frac{1}{2}$″ would have been measured to the left of IV; if $D/_8$, one eighth of 2″, and so on.

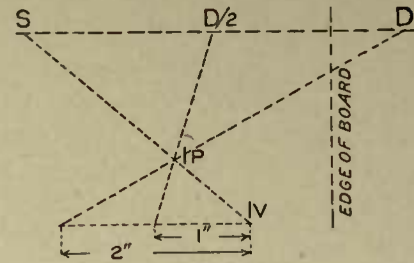


Fig. 156

PERSPECTIVE.

141. Another Example. — When none of the lines of the figure are parallel or perpendicular to the picture plane, more construction lines are needed, but the process is the same. Figure 157 shows a pyramid with its axis vertical and one edge of the base inclined to the picture plane.

The top and front views, ground line, horizon, S and D, are assumed in advance. Reduced points of distance are used. Each point of the front view is joined to S by dotted lines, and the points are located in perspective as shown in the last article. The only point needing explanation is the vertex. 5V is so near the horizon that it is best to project it to the ground line, perform the construction there for deter-

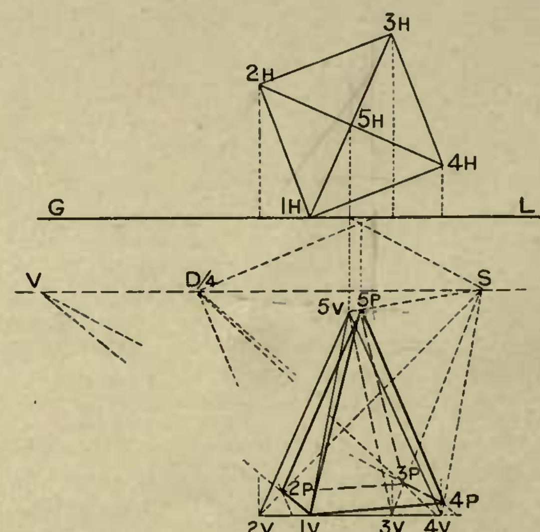


Fig. 157

mining the perspective, and project down to 5P. The vanishing points of the opposite sides of the base are at V and V′ in the horizon. Only V is shown in Figure 157, as the other point falls beyond the limits of the figure.

142. Circles in Perspective.—All circles will appear as ellipses unless their plane is parallel to the picture plane. The best method of drawing them is to construct a circumscribing square and sketch the ellipse freehand through eight points, which can be easily determined. Figure 158 shows a cube with one face in the picture plane and a circle inscribed in each face. The eight points through which each ellipse passes are evident by inspection.

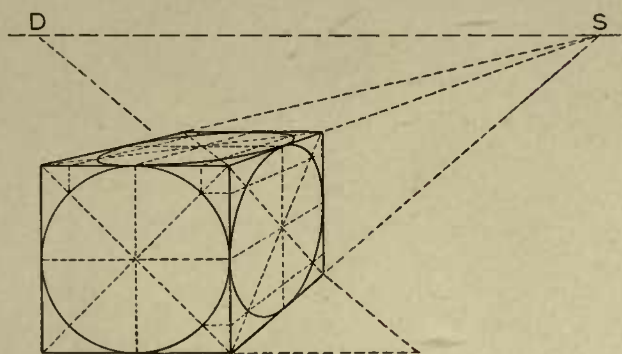


Fig. 158

Figure 159 shows the same cube with inscribed circles when no face is parallel to the picture plane. No explanation is needed, as the construction is evident from the figure. It is possible to obtain the major and minor axes of the ellipse, but for practical work it is not necessary.

A good example of a circle which appears as an ellipse in true perspective is furnished by Fig. 103, page 72.

143. Spacing Equal Distances.—The following is a useful method of spacing equal distances in perspective. Figure 160 shows the method applied to a line converging towards S. Lines 1 and 2 are

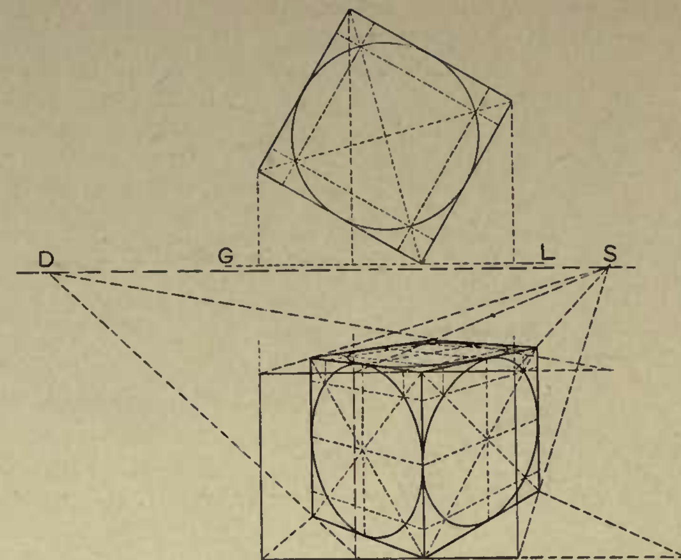


Fig. 159

given, and it is required to draw others, parallel and equidistant. Join 2 to any convenient point, V in the horizon, and produce to 1′. 1–1′ is a horizontal line. Draw a line from 1′ to S, which gives 2′ on a horizontal through 2. Join 2′ to V and get 3. Repeat the operation, and any desired number of points can be obtained.

The ordinary way of measuring would be cumbersome in this case, if many equal divisions were required.

144. Choosing the Point of Sight and Points of Distance. — While the choice of these points is entirely arbitrary, some general directions may be given. It should be remembered that the distance from S to D is the actual distance from the eye to the picture plane. This depends on the size of the paper, and is frequently made about twice the

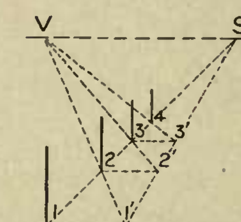


Fig. 160

diagonal of the sheet. If the distance is made too small, the result is a picture having "steep perspective."

A single large object, a house for example, should be viewed from a distance equal to at least twice its greatest dimension. If, for example, the height were 40 feet, the point of view might well be 80 feet away. Then the plan and elevation drawn to a scale of 4 feet to the inch would make S to D equal to 20 inches, and produce a perspective drawing something less than 10 inches high.

It is generally best to place the point of sight nearly in front of a large object, as a building, in order to get the most natural appearance. The plan must then be inclined to the picture plane. An easier but less satisfactory way is to place one face of the object in the picture plane and station the eye to one side. This is shown for a skeleton house in Figure 161.

Figure 162 shows the more approved arrangement. A sufficient number of dotted lines are given to explain the principal constructions.

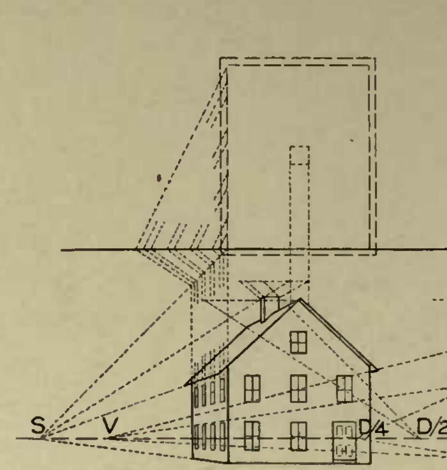


Fig. 161

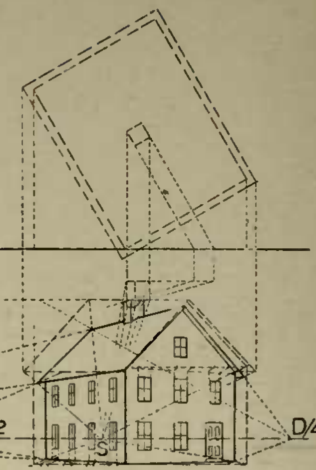


Fig. 162

CHAPTER VIII

WORKING DRAWINGS

145. A drawing is a *working drawing* when it gives all the information necessary to make the object it represents. A working drawing may be divided into three parts:

(1) The outline drawing showing the shape of the object.

(2) The dimensions giving the size of every part.

(3) The lettering—*i. e.*, printed explanations and directions.

A working drawing should be so complete that one can make the object from it without asking questions. It is evident, then, that dimensions and printed notes are essential parts of such a drawing.

If working drawings are made according to some common method understood and agreed upon by those who use them, the advantage to all concerned is obvious. Hence the development from the crude freehand sketch to the modern shop or working drawing.

While the method of making a working drawing varies somewhat in its minor details, the general method is everywhere the same. Hence there are certain definite rules by which the draftsman must be governed if he wishes his drawing to conform to the standard practice. The most important of these rules can be observed by the student at the outset. A manufacturing company often requires its draftsmen to observe certain customs adapted to its own work; these simply supplement the rules above referred to.

146. In making a working drawing the aim should be:

(1) To make it conform to the standard practice.

(2) To show the shape and give the size of every part of the object.

(3) To answer in advance all reasonable questions one might ask in making the object.

(4) To work quickly without sacrificing accuracy or neatness.

147. In working drawings the object is represented by two or more views, each of which is drawn according to the principles of orthographic projection (Chaps. V. and VI.). Hence these views are really projections, *not pictures* (Art. 62 *c*). As many such views are shown as may be necessary to completely represent the object (Art. 62). The arrangement of views depends on which angle of projection is used (Arts. 61 *c* and 64 *b*). In the third angle the top view is drawn above the front view, the bottom view below the front view, the end view nearest the end it represents, and so on. In the first angle the positions of the views are reversed—the top view is below the front view, the bottom view above it, and so on. Since both methods of arrangement are used, it is well to mark each view, as, for example, END VIEW, TOP VIEW, etc.

REMARK: Experienced draftsmen seldom think of the planes of projection at all (Art. 64 *d*).

Ground lines are usually omitted, and the distance of the object from H or V respectively is immaterial.

When a section view is drawn the point at which the section is taken is indicated on one of the other views. The usual way is to draw the trace of the cutting-plane, lettering it, and marking the section view to correspond, as, for example, SECTION AT AA. (See section view, Plate 1, page 101.)

The portion of the object behind the cutting-plane is shown in the section view when it helps to explain the section, otherwise it is omitted.

When an object is symmetrical with respect to an axis, and a section view is needed, it is often sufficient to show a half section combined with a half of another view. Thus, in Figure 163, a half end and a half section view is shown.

For the location of a section view no rigid rule can be followed; the draftsman is often obliged to place it in some particular space by the arrangement of the other views. If possible the following arrangement should be observed when the portion of the object back of the cutting-plane is shown: A section seen from above occupies the same position as a top view; looking from the right towards the left—the same position as a right-hand end or side view; from below—the same position as a bottom view, and so on. When the section view shows only the portion of the object cut, its location is of little importance, but, in general, it should be as near as possible to the view which shows where the section is taken.

148. The Drawing—To Show the Shape.—The drawing shows the shape of the object. It may be made to any convenient scale, as full size, half size, quarter size, and so on. In drawings of large objects scales of $\frac{3}{4}'' = 1'\text{-}0''$, or $1'' = 1'\text{-}0''$, or $1\frac{1}{2}'' = 1'\text{-}0''$, or $3'' = 1'\text{-}0''$ are commonly used. In this case measurements on the drawing are best laid off by means of the "Architects' Open Divided Scale." (See Art. 21.)

Shop units are feet and inches, and halves, quarters, eighths, sixteenths, and thirty-seconds of an inch; the decimal scale is, therefore, not often used in working drawings.

Drawings are first made in pencil. If a number of copies are required, instead of inking the drawing on the original sheet a tracing is made (Art. 43) and blue prints taken (Art. 42). Experienced draftsmen often make the drawing directly on the tracing-linen itself. The size of the sheet depends upon the nature of the drawing. Sheets $36'' \times 24''$ and under are preferable to those of larger size if the limits of the drawing will permit. If several different sheets of drawings of the same object are needed, it is well to make them all of one size.

A drawing which represents the object as it will appear when finished, with each part in its proper place, is called an "*assembled drawing*." A "*detail drawing*" shows each part by itself. In the latter case parts adjacent in the object should, in general, be near each other in the drawing. Small details are sometimes shown by themselves to larger scale if clearness is gained thereby. Parts made on the same machine or by similar processes are often collected on separate sheets. (Thus there may be sheets of bolts, screws, forgings, castings, etc.) This is only done where large numbers of pieces are wanted and their manufacture has been somewhat systematized.

When an object is symmetrical it is often sufficient to show one-half of it. Long pieces can frequently be "broken" to save space and still show all that is necessary if the *true* dimensions are given. (See blade of T-square, Fig. 163.) When two pieces differ only in being rights and lefts, it is usually necessary to draw but one of them, noting on the drawing that two are wanted—one right and one left.

Remark: Two pieces are right and left in the same sense that the two hands are right and left. When placed side by side they are symmetrical with respect to an imaginary straight line between them, but when placed one on top of the other they do not coincide. It usually makes no difference *which* is called a right—simply designate one the right, the other the left.

Invisible lines are usually shown, unless the clearness of the drawing is sacrificed thereby. For example, if the top and bottom views of an object are both shown, details on the bottom, which would lead to confusion if shown in the top view, are omitted altogether in the top view, but are shown in the bottom view, where they appear as full lines.

Open bolt and rivet holes are usually blackened, or if large they are cross-lined ("hatched"). Shade-lines may be drawn as explained in Article 128. Some draftsmen omit them altogether. Cylindrical surfaces may be shaded, according to Article 37. Sometimes, in the drawing of one part of an object, a second part connecting with it and not otherwise shown is indicated by broken lines throughout to show better the connection.

149. Dimensions—Size of an Object.—The size of every part of an object is given by the dimension figures and lines. Dimension lines show exactly from what point to what point the measurement is to be made. (See Fig. 163.) Such lines should be distinguished from the regular lines of the drawing. They are usually drawn in one of three ways: (1) Fine broken lines (Fig. 163). (2) Very fine black lines. (3) Red lines. Red lines of tracings print more faintly on blue process paper than do the black lines, and this has the effect of making the drawing itself stand out with the dimension lines in

the background. Dimension figures and the arrow heads at the ends of a dimension line, however, *should always be black.*

Figures should be plain, heavy, and unmistakable—*words can be guessed at, but not figures.* It is better to leave a space in the middle of each dimension line for the dimension, than to write the figures above or below the line. If a dimension line is so short that a dimension cannot be given on it, the latter is placed to one side and an arrow indicates where it belongs. *The dimensions on a drawing are those of the object represented,* no matter what the scale may be. Thus, for example, an inch on the drawing may be marked 1′–0″ if the corresponding dimension of the object is a foot.

Any dimension less than a foot is given in inches, *not* in decimal parts of a foot. Anything less than an inch is given by the nearest vulgar fraction whose denominator is 64, 32, 16, 8, 4, or 2, *not* by any other fraction whose denominator is not one of these numbers nor by a decimal. Thus, for example, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{3}{8}$, $\frac{9}{16}$, $\frac{13}{32}$, $\frac{19}{64}$, *but not* $\frac{1}{3}$, $\frac{2}{5}$, $\frac{5}{7}$, $\frac{8}{9}$, etc.

REMARK: Draftsmen often use decimals *in computing* dimensions, changing a fraction of an inch to a decimal part of an inch, or inches to a decimal part of a foot, and *vice versa*, by means of tables designed for that purpose. As a rule, the line between the numerator and denominator of a fraction should *not* be oblique.

Feet and inches are indicated thus, 6′–3″. It is better to give anything twelve inches and over in feet and inches. Custom varies in this respect. Widths of boards, iron plates, etc., are given in inches when writing down the three dimensions, as, for example, $14'' \times \frac{1}{2}'' \times 10'$–$0''$. In such a case the order of dimensions is width × thickness × length. The width being given first, and assumed at right angle to the "grain," the direction of the latter is thus determined. Thus, in a $14'' \times \frac{1}{4}'' \times 8''$ piece, the grain is parallel to the 8″ edge. In iron the width of a plate is at right angles to the rolled edge, and in many cases, as in bending, it is important to know which dimension is the width.

If a dimension is in even feet, or in feet and a fraction of an inch, the 0″ should be noted. For example, 2′–0″, or 1′–0″, or 1′–0$\frac{1}{8}$″, *not* 2′, nor 1′, nor 1′–$\frac{1}{8}$″, nor 12$\frac{1}{8}$″.

Dimensions should be put on the drawing *as fast as they are used in making it.* It is a bad plan to wait until the drawing is finished before putting them on, as some are apt to be omitted.

The very same dimensions used in making the drawing (perhaps more) will probably be needed in making the object. A draftsman needs to look at his drawing from the standpoint of the workman to make sure of noting all the dimensions needed.

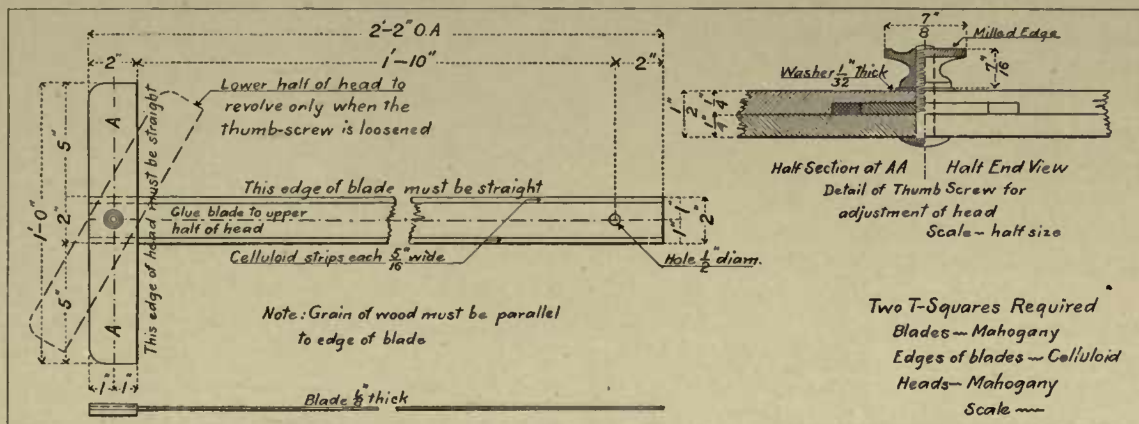


FIG. 163

Long dimensions are put on first, and these are subdivided and re-subdivided as may be necessary. Care is necessary to make the subdivisions "foot up" the longer length. In Figure 163 the 2′–2″ was first put on, then the 2″+1′–10″+2″=2′–2″, and so on.

In order that a line of dimensions may be readily footed up, it should, if possible, be continuous from end to end, as, for example, the line above referred to in Figure 163. Dimension lines should not cross each other when it can be avoided; if such lines must cross, do not mark the length of either near their point of intersection. Dimension lines should stop at exactly the right place. If necessary, make the dimension more definite by a note, as, for example, 2′–3″ C to C of holes.

Draw centre lines, such as axes of symmetry, with long and short dashes — alternating (Art. 32 *c*, page 33). Many dimensions can be referred to such lines. Do not give unnecessary dimensions nor repeat the same one in different views unless a positive gain of clearness is made thereby. "Over all dimensions" are of considerable importance to save the workman the trouble of "footing up" or adding together a number of smaller lengths.

In certain classes of work angles are given in degrees. In others, however, they are given by the length of the perpendicular when the base is a foot. This is easily found from the natural tangent of the angle (Fig. 14, page 38). If it is desired to give the angle exactly it is sometimes necessary to assume a base of more than a foot. It should always be noted, therefore, whether it is a foot or more by giving both sides of the triangle.

ILLUSTRATION: Let it be required to give an angle of 30°. The natural tangent of 30° is 0.5774. If the base is a foot the perpendicular is 0.5774 of a foot. 0.5774 of a foot is nearly $6\frac{15}{16}$ inches. Hence for an angle of 30° the rise is $6\frac{15}{16}$ inches per foot.

The size of a small hole is given by a note, as, for example: "Hole $1\frac{1}{4}$″ in diameter." It often happens that when several successive dimensions are alike they can all be given by a single note. For example, suppose that there are twelve rivet holes in a straight line, the distance between two adjacent holes being six inches. Instead of putting down the dimension 6″ eleven times, draw a dimension line parallel to the line of holes, and extending between the lines drawn out from the centres of the two end holes; on this line note:

11–spaces @ 6″=5′–6″; or, another form, 5′–6″=11–6″ spaces.

A drawing is usually made to scale, but if scale and dimensions as given do not agree, dimensions are assumed to be correct and govern the men in the shop. In some shops workmen are not allowed to scale drawings, but must use only the written dimensions. In such places it is not of so much importance whether the drawing is exactly to scale or not. In all shop drawings, however, it is absolutely essential that each dimension be definite and correct.

150. NOTES—QUESTIONS ANSWERED.—The workman should have all questions which he may need to ask answered on the drawing itself. Notes giving all the necessary information are, therefore, an important part of a working drawing. Such notes are printed in the vacant spaces, care being taken to avoid a crowded appearance. They should be so printed as to be easily read from the *bottom* and *right-hand* edges of the sheet, *i. e.*, as a rule, from left to right and from the bottom up. An arrow is frequently used to indicate to what part of the object a note applies. Abbreviations are often used, such as: E to E (end to end), O A (over all), C to C (centre to centre), and many others learned only from practical experience.

The lettering should be plain freehand, with all words and figures perfectly legible (Art. 33). Script writing should be avoided.

Notes should be given stating the material used, how each part is to be finished, and the number of pieces required. Special directions pertaining to the making, painting, shipping, etc., are given in notes on the drawing. In the case of large structures, like bridges and buildings, it may also be necessary to put on notes pertaining to erection.

Some of the standard form of notes are as follows:

THE HALF NOT SHOWN EXACTLY LIKE THE HALF SHOWN.

ALL DIMENSIONS ON THIS HALF SAME AS FOR THE OTHER HALF EXCEPT WHEN MARKED OTHERWISE.

ALL MATERIAL OAK UNLESS OTHERWISE MARKED.

PLANE THE TWO ENDS TO PERFECT CONTACT.

CLIP CORNER 6″ EACH WAY.

ALL BOLTS ½″ DIAM. UNLESS OTHERWISE SPECIFIED.

BOLT TOGETHER FOR SHIPMENT.

TWELVE PIECES LIKE THIS REQUIRED.

These are a few of the many standard notes found on working drawings. They are given to call the attention of the beginner to the fact that there are certain customary forms for such notes. For example, the clause "unless otherwise marked" or "unless otherwise specified" is a saving clause often necessary to the first part of the note. To learn these notes, however, nothing is better than a study of good examples in actual working drawings.

Every class of work has its own peculiar notes. For example, the machine draftsman notes *f all over* when a whole piece is to have a machine finish. The bridge draftsman notes *Four pieces required. 2–Mark AR, 2–Mark AL differ only in being rights and lefts.* (Different members of a bridge are marked with paint before leaving the shop, each with the letters called for on the drawing, to facilitate erection.) In the same way characteristic notes could be cited from other classes of work.

Titles are printed in the lower right-hand corner of the sheet. As a rule, elaborate titles are to be avoided. Use freehand letters, the largest letters for the most important words, the next largest for the next important, and so on. For example:

DETAILS OF A

BOOK CASE

SCALE: ¼ SIZE

Sheet 2 of 4 Sheets

For material and finish, see Sheet 1

When there are more than two sheets, number each one and give the total number of sheets. Notes pertaining to material, general finish, etc., are usually printed on one sheet only. The scale is often omitted, the word "scale" followed by a dash signifying that the drawing is to scale, but that there are reasons for not giving it.

The notes on a drawing form a set of specifications and should be definite. It is more difficult to word a note so that it cannot be misunderstood than at first appears. The aim should be to make everything so clear and unmistakable that the most stupid man in the shop will understand exactly what is wanted.

SUGGESTIONS

If one view shows a larger portion of the object in its *true* shape and size than any other view, start that view first.

Estimate the space each view will occupy and draw centre lines, allowing space enough between views for dimensions.

Build up each view about its centre lines.

Project lines from one view to another to save work with the scale.

It is often impossible to complete one view at a time, and in many cases it is necessary to carry along two or more views simultaneously.

Draw the main outlines first, details last.

Be sure important measurements to centre lines, etc., are correct before putting in dimensions of smaller details depending on them.

If a dimension is altered, change *all* dimensions related to or depending upon it to correspond.

Order of inking: Arcs of circles, irregular curves, straight lines, centre lines, dimension lines, dimensions, section lining, notes, title, and border line.

For directions for the use of the instruments, for precautions to insure neatness, hints for rapid drafting, directions for laying off measurements, line notation, lettering the drawing, mixing of inks, shade lines, section lines, tracing, blue printing, constructions for parabola, hyperbola, and ellipse, etc., see Chapters II. and III.

PLATES

When a workman is making an object from a working drawing, he must find the answer to his questions, "What shape?" "How long?" "How wide?" "How deep?" "What material?" "How put together?" etc., on the drawing itself. The primary object, then, of a working drawing is to answer questions. As an illustration of how the student should study such a drawing, the following questions are given, the answers to which are to be found on the working drawing of the card file (Plate I.).

THE BOX

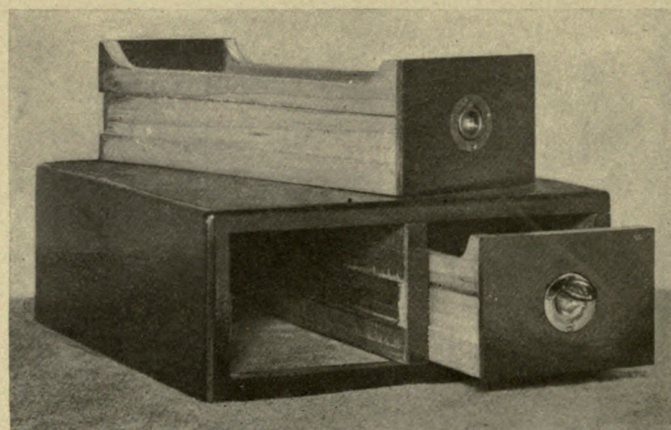
Shape? Length O. A.? Width O. A.? Depth O. A.?
Three dimensions of Top? Bottom? Sides? Partition?
Width and depth in the clear of each compartment?
Location and size of sliding strips for each drawer?
How are corners of box fitted and held together?

THE DRAWER

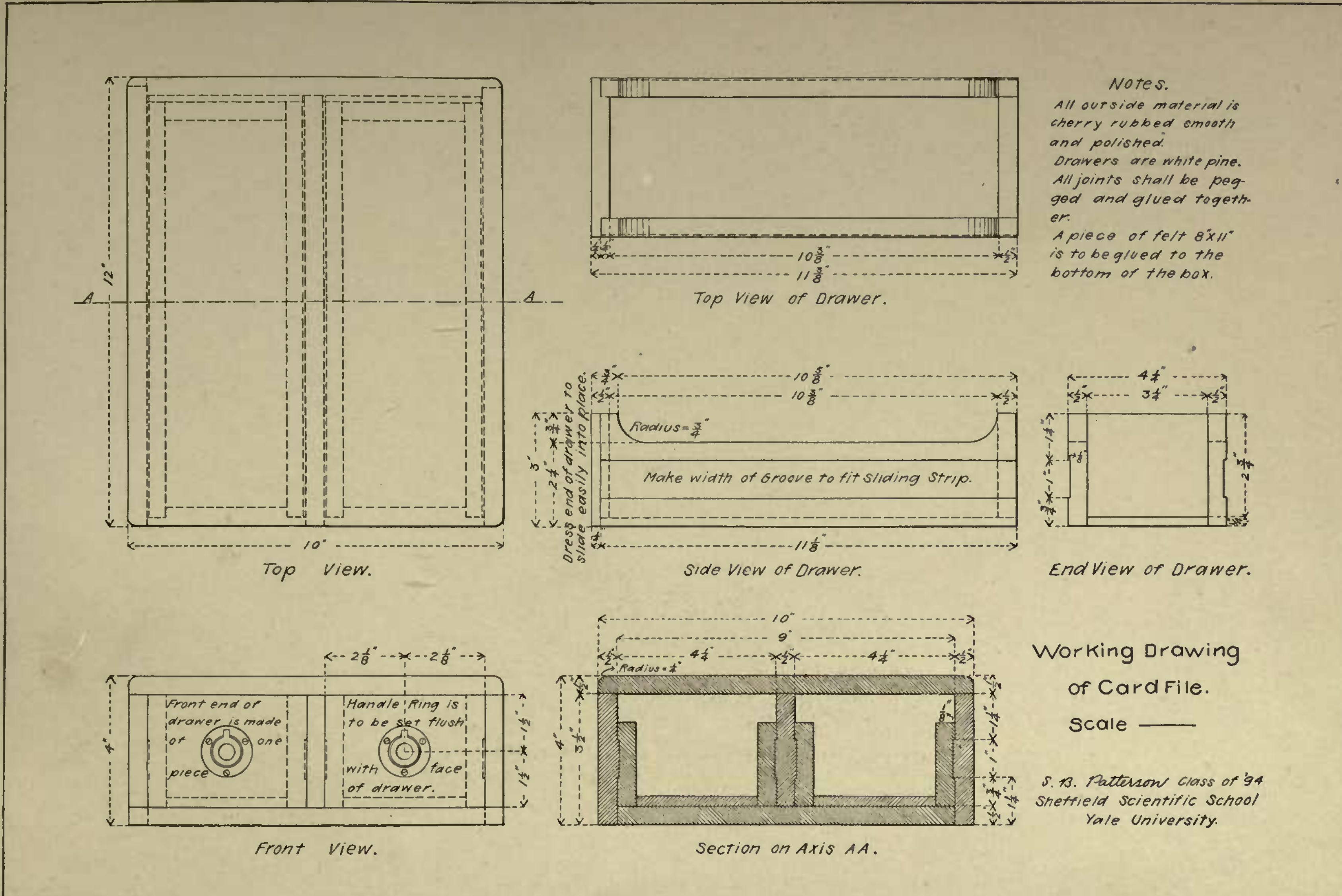
Shape?
Size and shape of sides? Front pieces? Back pieces? Bottom?
How are the back and front pieces fastened to side pieces?
Width and location of grooves for sliding strips?
Location, shape, and size of handle?

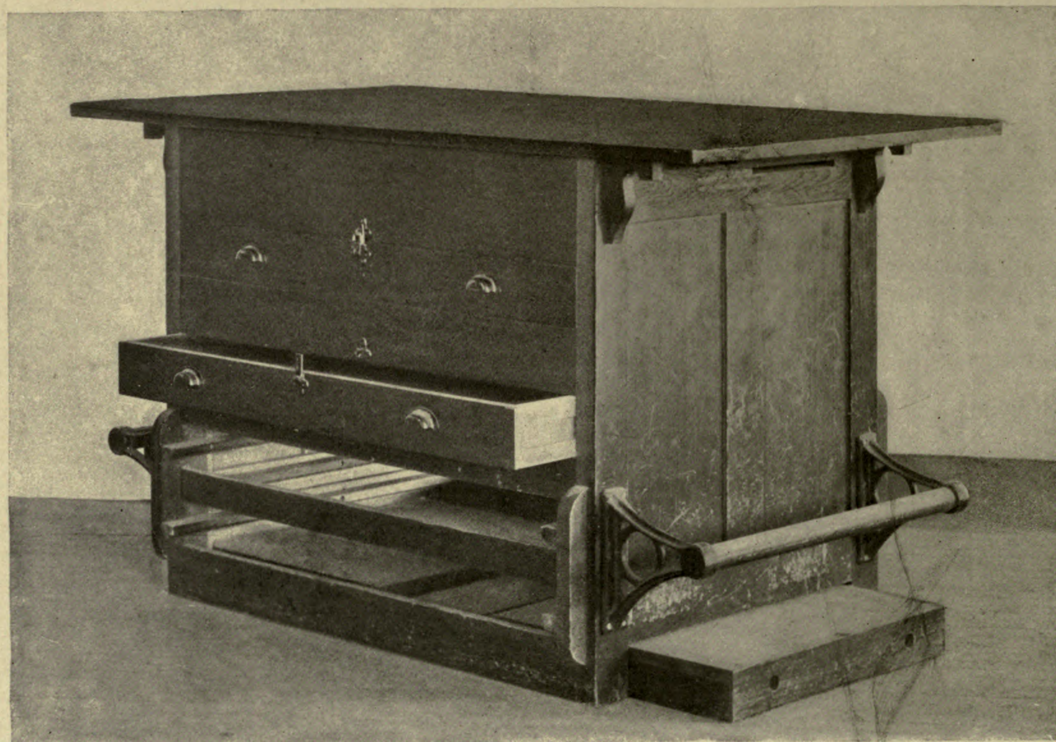
GENERAL DIRECTIONS

What is glued to bottom of box? Material for box? Material for drawer? Outside finish?

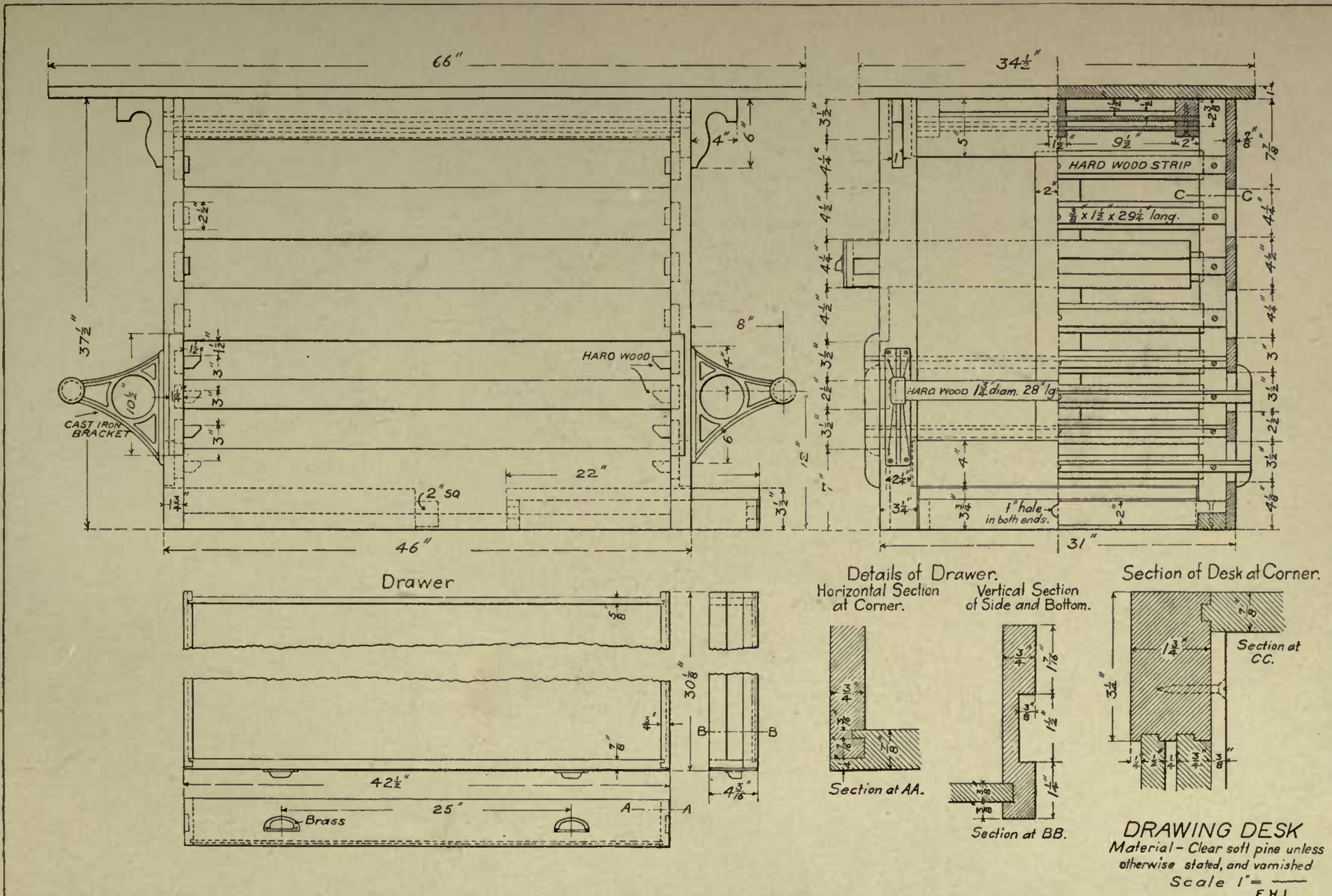


Card File (Plate I.)

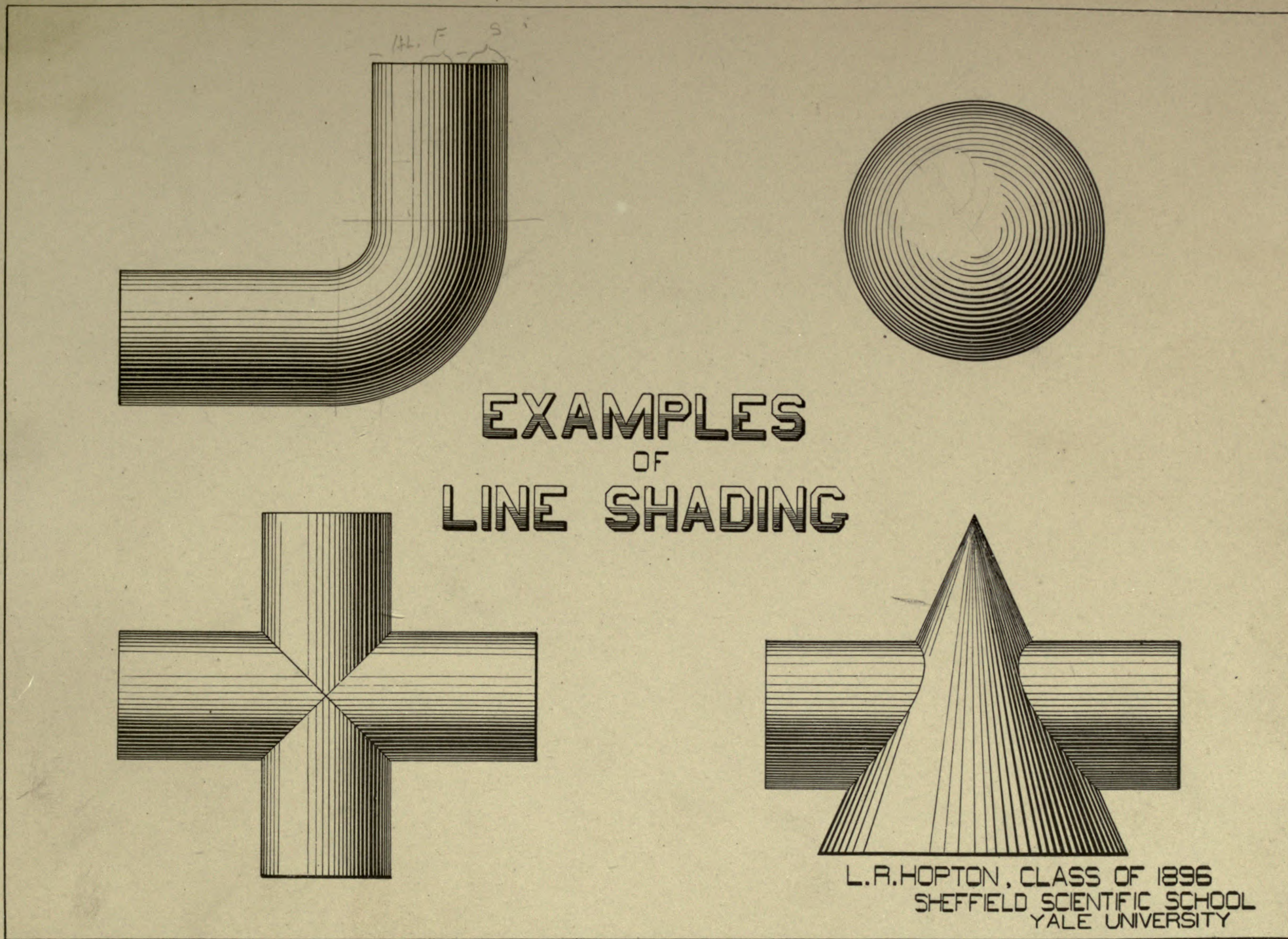

Notes.
All outside material is cherry rubbed smooth and polished.
Drawers are white pine.
All joints shall be pegged and glued together.
A piece of felt 8"x11" is to be glued to the bottom of the box.
Top View.
Top View of Drawer.
Radius = 3/4"
Make width of Groove to fit Sliding Strip.
Dress end of drawer to slide easily into place.
Side View of Drawer.
End View of Drawer.
Front end of drawer is made of one piece
Handle Ring is to be set flush with face of drawer.
Front View.
Radius = 1/4"
Section on Axis AA.
Working Drawing of Card File.
Scale
S. B. Patterson Class of '94
Sheffield Scientific School
Yale University.

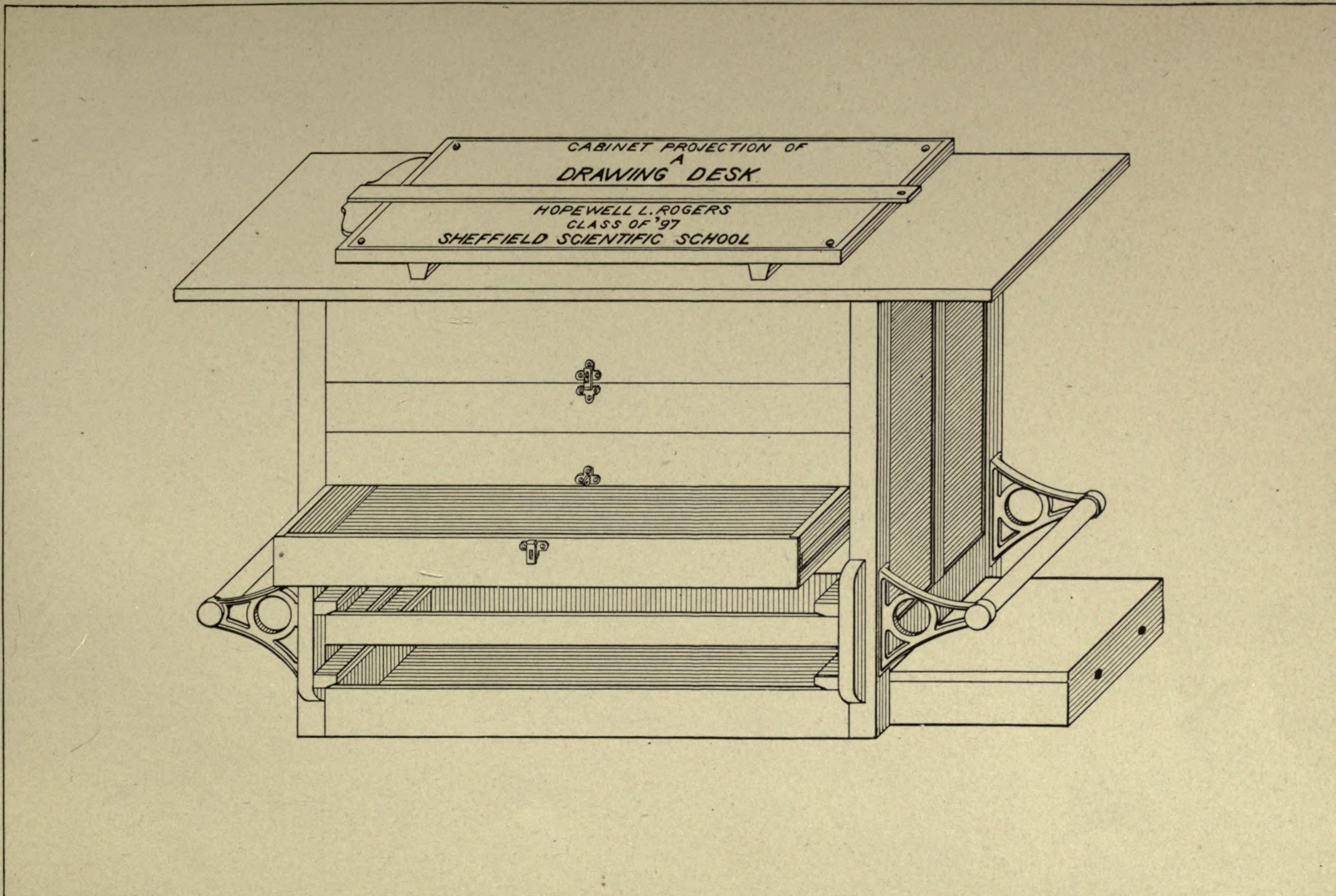


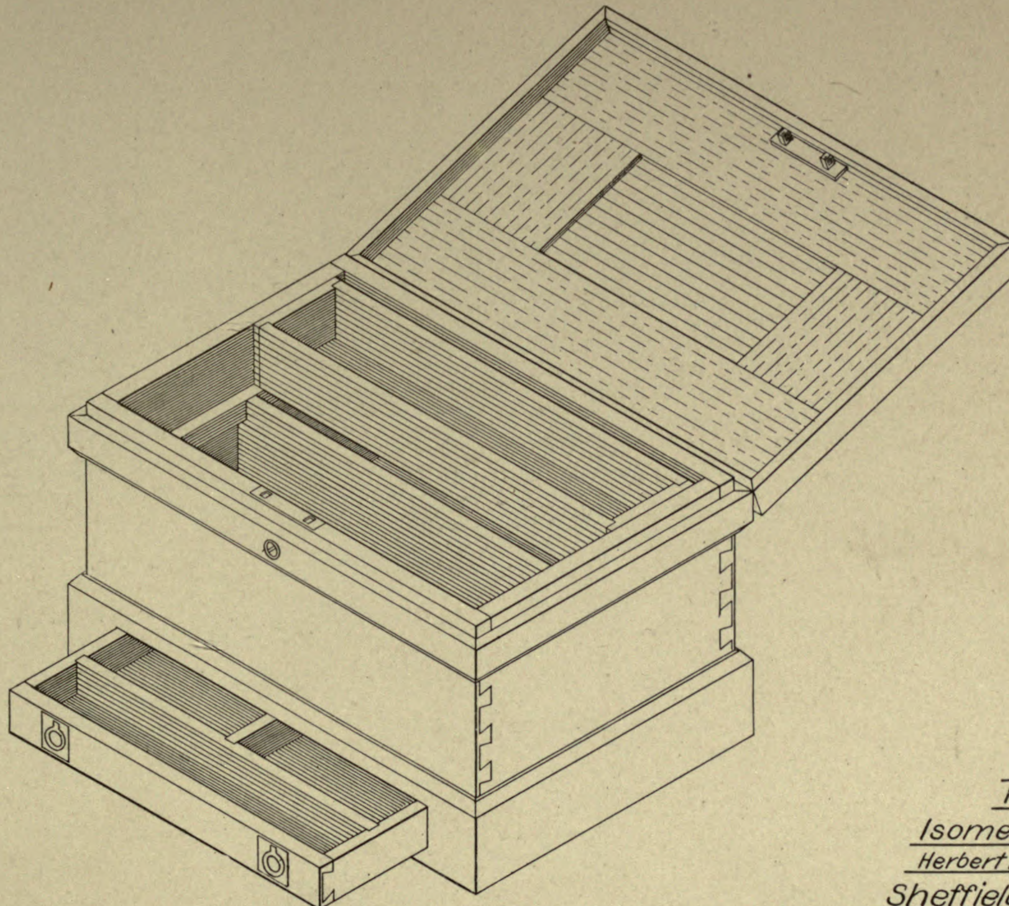
Drawing-desk Made from the Working Drawing on the Opposite Page



CAST IRON BRACKET
HARD WOOD
HARD WOOD STRIP
HARD WOOD 1¾" diam. 28" lg.
1" hole in both ends.
Drawer
Brass
Details of Drawer.
Horizontal Section at Corner.
Vertical Section of Side and Bottom.
Section at AA.
Section at BB.
Section of Desk at Corner.
Section at CC.
DRAWING DESK
Material – Clear soft pine unless otherwise stated, and varnished
Scale 1" =
E.H.L.


EXAMPLES
OF
LINE SHADING
L. R. HOPTON, CLASS OF 1896
SHEFFIELD SCIENTIFIC SCHOOL
YALE UNIVERSITY


CABINET PROJECTION OF
A
DRAWING DESK
HOPEWELL L. ROGERS
CLASS OF '97
SHEFFIELD SCIENTIFIC SCHOOL



Tool Chest.
Isometric Projection.
Herbert Hastings, Class of 98.
Sheffield Scientific School
Yale University.

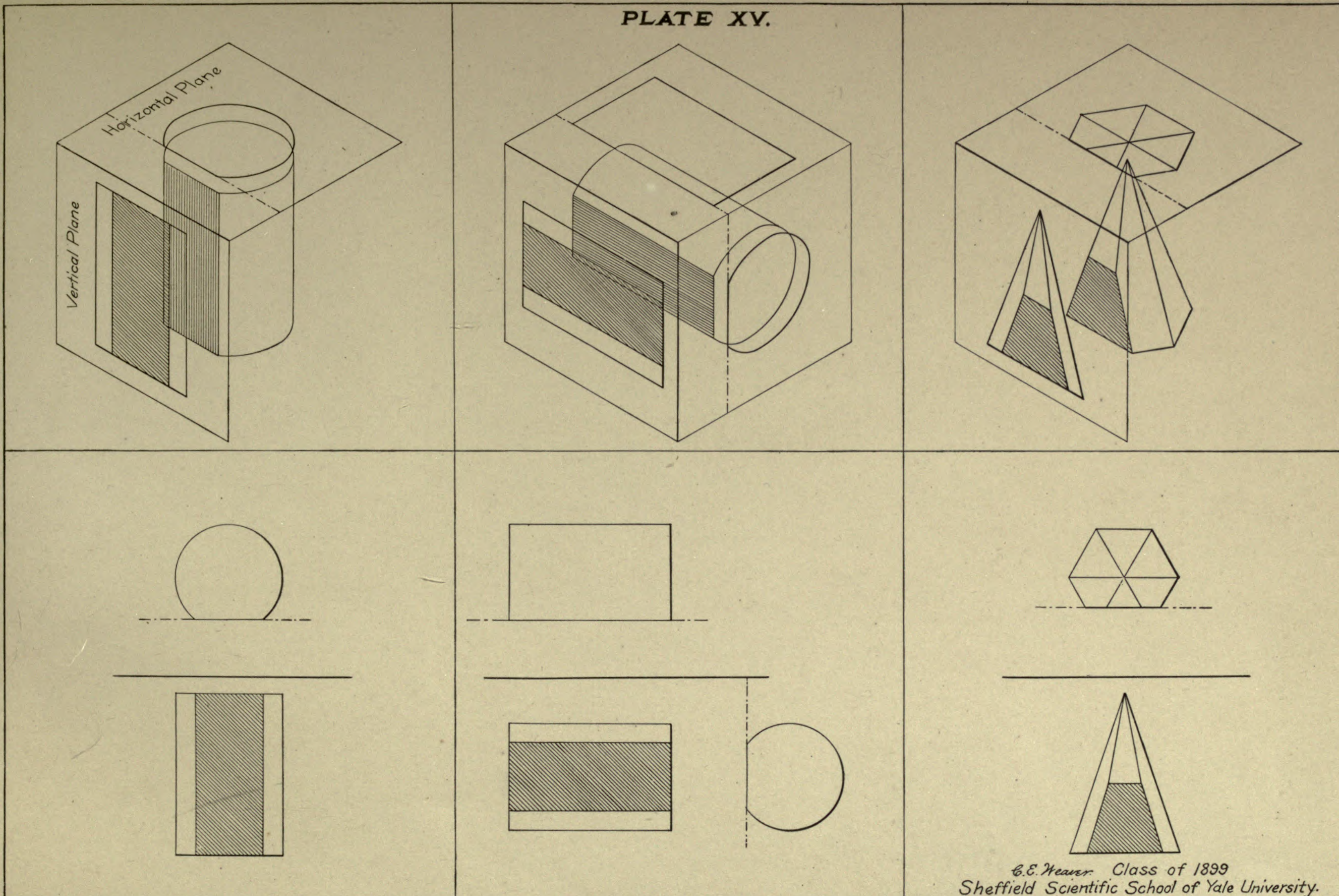
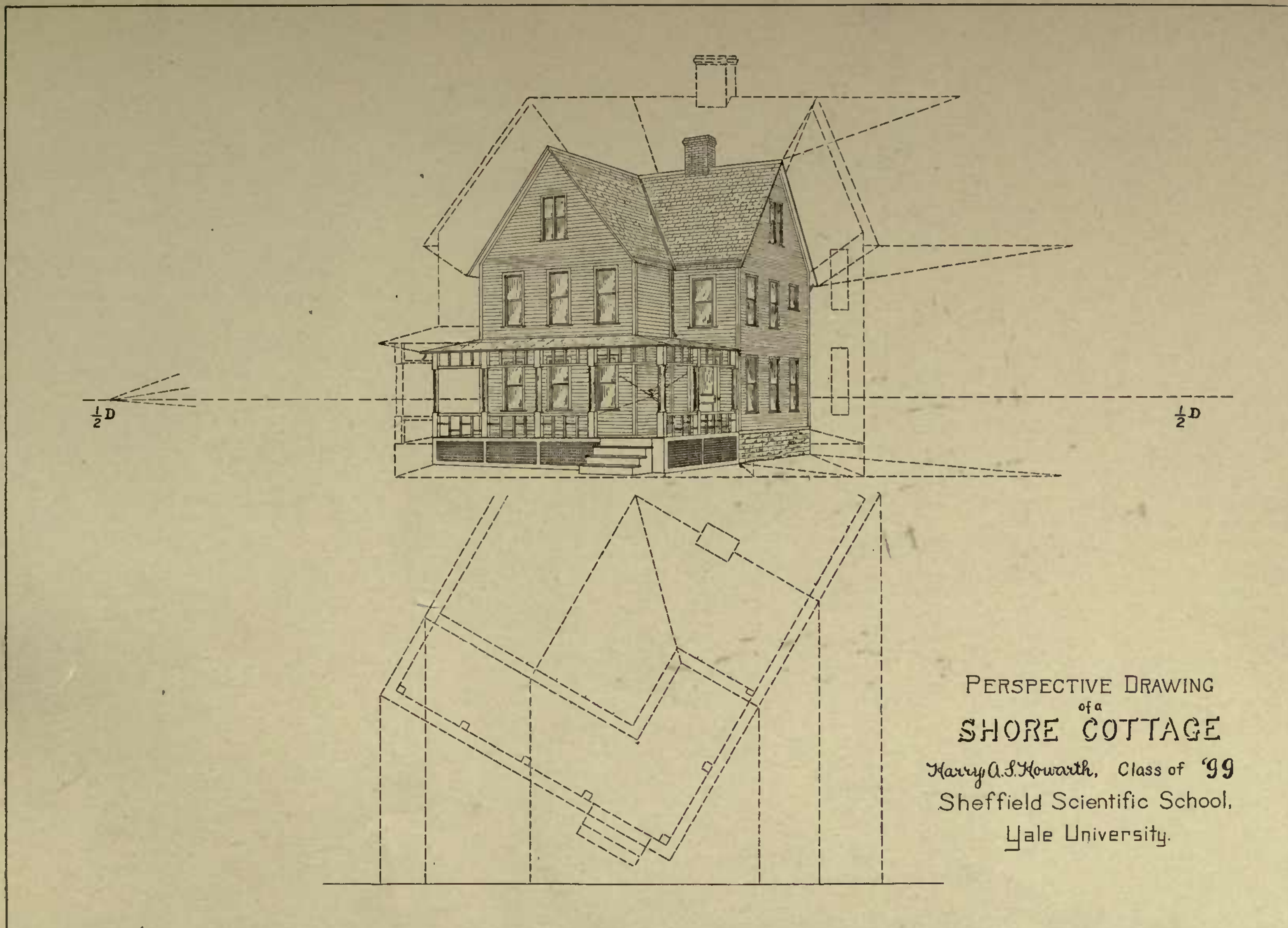
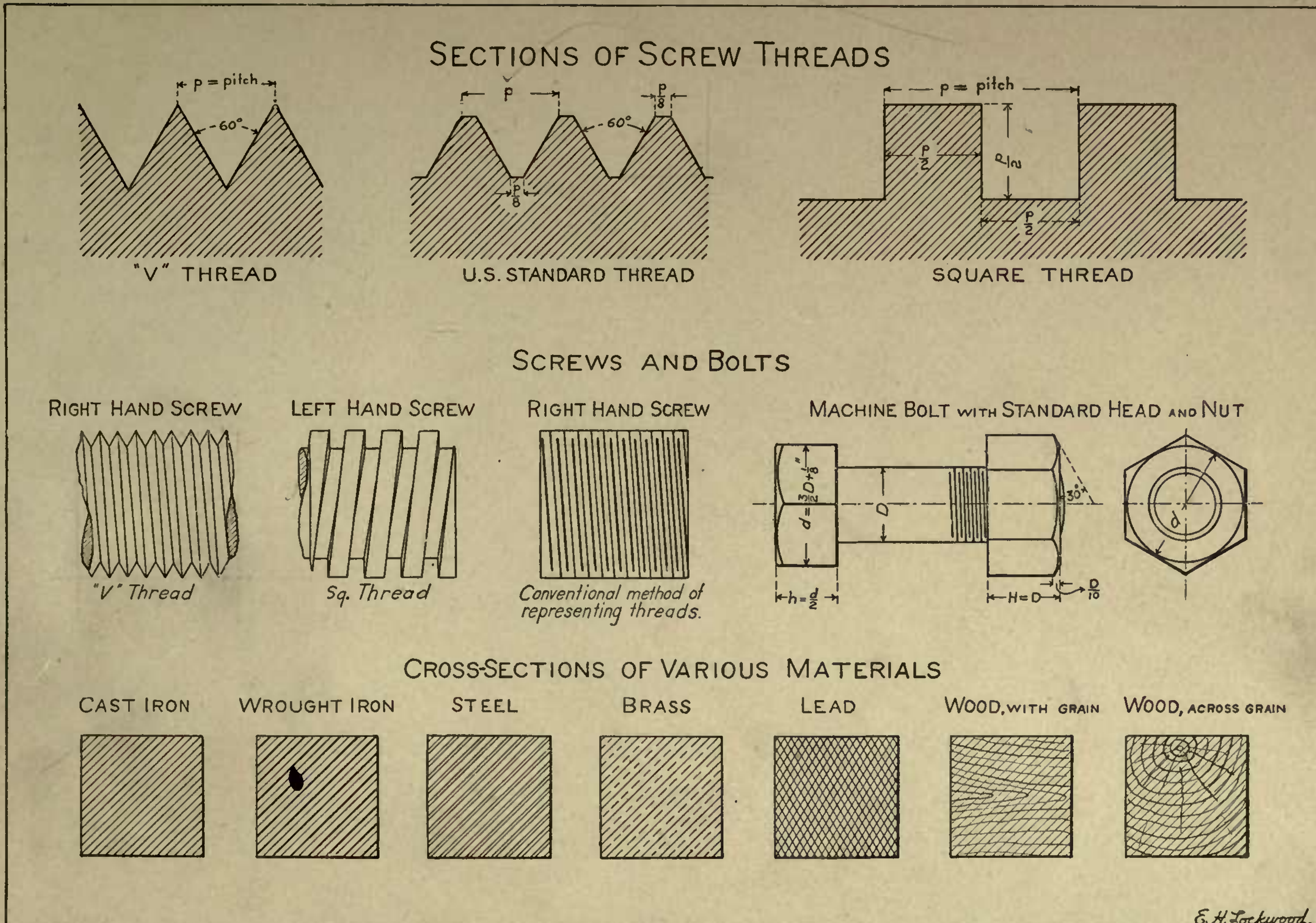


PLATE XV.
Horizontal Plane
Vertical Plane
C. E. Weaver Class of 1899
Sheffield Scientific School of Yale University.


½ D
½ D
PERSPECTIVE DRAWING
of a
SHORE COTTAGE
Harry A. S. Howarth, Class of '99
Sheffield Scientific School,
Yale University.


SECTIONS OF SCREW THREADS
p = pitch
60°
"V" THREAD
p
P/8
60°
U.S. STANDARD THREAD
p = pitch
P/2
SQUARE THREAD
SCREWS AND BOLTS
RIGHT HAND SCREW
"V" Thread
LEFT HAND SCREW
Sq. Thread
RIGHT HAND SCREW
Conventional method of representing threads.
MACHINE BOLT WITH STANDARD HEAD AND NUT
d = 3/2 D + 1/8"
D
30°
h = d/2
H = D
D/10
d
CROSS-SECTIONS OF VARIOUS MATERIALS
CAST IRON
WROUGHT IRON
STEEL
BRASS
LEAD
WOOD, WITH GRAIN
WOOD, ACROSS GRAIN
E. H. Lockwood.